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Birmingham and Midland Bank, Birmingham.

SECRETARY.

William P. Marshall.

Assistant Secretary.—Alfred Bache,

Institution of Mechanical Engineers,

81 *Newhall Street, Birmingham.*

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1876.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, 4 Delahay Street, Westminster, S.W.
1876. Adams, Henry, Assistant Engineer, Sir Wm. G. Armstrong and Co., 8 Great George Street, Westminster, S.W.
1875. Adams, Thomas, Ant and Bee Works, West Gorton, Manchester.
1848. Adams, William Alexander, Walford Manor, near Shrewsbury.
1859. Adamson, Daniel, Engineering Works, Hyde Junction, near Manchester; and The Towers, Didsbury, near Manchester.
1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester.
1861. Addenbrooke, George, Ashville Hington, Leamington.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste. Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, Poste Restante, Cape Town, Cape of Good Hope : or Corinium Iron Works, Cirencester.
1847. Allan, Alexander, Kenilworth Villa, South Cliff, Scarborough.
1875. Allan, George, Savile Street Engineering Works, Sheffield.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Engineer and Contractor, Moscow: (or care of Messrs. Carruthers and Alley, 88 Bath Street, Glasgow.)
1865. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.
1876. Allport, Charles James, Manager, Messrs. John Brown and Co.'s, Atlas Steel Works, Sheffield.

1871. Allport, Howard Aston, Bestwood Coal and Iron Co., 40 Elm Avenue, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1876. Anderson, Henry John Card, Manager of Sugar Mills of the Viceroy of Egypt, Cairo, Egypt.
1856. Anderson, John, LL.D., F.R.S.E., 22 Victoria Road, Old Charlton, London, S.E.
1856. Anderson, William, Messrs. Eastons and Anderson, Erith Iron Works, Erith, London, S.E.
1858. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.
1867. Appleby, Charles James, Messrs. Appleby Brothers, Emerson Street, Southwark, London, S.E.
1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid.
1874. Archer, David, General Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.
1859. Armitage, William James, Farnley Iron Works, Leeds; and Southgate House, Southgate, Middlesex, N.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.
1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.
1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.
1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham.
1857. Ashbury, James Lloyd, M.P., 66 Grosvenor Street, London, W.
1873. Ashbury, Thomas, Managing Director, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester.
1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.
1875. Atkinson, Edward, Assistant Manager, Messrs. Fletcher Jennings and Co.'s, Lowca Engine Works, Whitehaven. (*Life Member.*)
1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.

1869. Aveling, Thomas, Messrs. Aveling and Porter. Rochester.
1874. Ayton, Frederick, Messrs. Ayton and Co., Eagle Brewery, Bishopbriggs, Glasgow.

1872. Bagshaw, Walter, Victoria Foundry, Batley.
1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, Perry Barr, Birmingham.
1872. Bailly, Philimond, 37 Rue des Fripiers, Brussels.
1873. Baird, George, Messrs. Baird, Iron Works, St. Petersburg ; and 5A Cork Street, Burlington Gardens, London, W.
1866. Baker, Samuel, Engine and Boiler Works, 22 Oil Street, Liverpool.
1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.
1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.
1870. Barclay, Arthur, 12 York Street, Covent Garden, London, W.C.
1860. Barclay, John, Bowling Iron Works, near Bradford.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.
1866. Barnard, Clement. 4 Billiter Square, London, E.C.
1862. Barrow, Joseph, Messrs. Smith Beacock and Tannett's Works, Victoria Foundry, Leeds.
1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.
1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth.
1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham ; and Elm Tree Villa, Smallheath, Birmingham.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1869. Beattie, William George, Locomotive and Carriage Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1859. Beck, Edward, Dallam Forge, Warrington ; and Palmyra Square, Warrington. (*Life Member.*)
1873. Beck, William Henry, 139 Cannon Street, London, E.C.
1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.
1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1865. Bell, Charles, Messrs. Palmer and Bell, Agricultural Engineers, Taganrog, South Russia; and 59 South Street, Greenwich, S.E.

1858. Bell, Isaac Lowthian, M.P., F.R.S., Clarence Iron Works, Middlesbrough; and Harlsey Hall, Northallerton.

1857. Bellhouse, Edward Taylor, Eagle Foundry and Iron Works, Hunt Street, Oxford Street, Manchester.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1873. Bentley, John Greenwood, Westfield Cottage, Penistone, near Sheffield.

1875. Berry, Francis, Messrs. Francis Berry and Sons, Calderdale Iron Works, Sowerby Bridge.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.; and Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.; and Haydon Bridge, near Carlisle.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1866. Birkbeck, John Addison, Grange Road, Middlesbrough.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1875. Bisset, William Harvey, Board of Trade Surveyor, 18 Canonbury Park Square, London, N.

1870. Blair, John, Chief Locomotive Superintendent, Danish Government Railways, Aarhuus, Denmark.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, near Warrington.

1863. Boeddinghaus, Julius, Machine Works and Iron Foundry, Düsseldorf, Germany.

1872. Boistel, Georges, 11 Rue de Châteaudun, Paris.

1872. Bolton, Major Francis John, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.

1869. Borrie, John, New Exchange Buildings, Middlesbrough.

1862. Bouch, Thomas, 111 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1869. Boyd, William, Wallsend Slipway Co., Wallsend, near Newcastle-on-Tyne.

1875. Braconnot, Capt. Carlos, Chief Director and Engineer of the Marine Arsenal, Correio Geral-Caixa 232, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1873. Bradbury, Charles Jordan, Heaton Terrace, Bury Old Road, Cheetham Hill, Manchester.

1875. Bradley, Isaac, Ammunition Works, Mill Lane, Ward End, Birmingham.

1854. Bragge, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield; and Shirle Hill, Sheffield.

1875. Braithwaite, Richard Charles, Manager, Old Park Iron Works, Wednesbury.

1854. Bramwell, Frederick Joseph, F.R.S., 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, Messrs. Breeden and Booth, 157 Cheapside, Birmingham.

1875. Broadbent, Thomas, Chapel Hill Iron Works, Huddersfield.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

1874. Brotherhood, Peter, Messrs. Brotherhood and Hardingham, 56 Compton Street, Goswell Road, London, E.C.; and 25 Ladbroke Gardens, Notting Hill, London, W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1853. Brown, Ralph, Patent Shaft Works, Wednesbury.

1869. Browne, Benjamin Chapman, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1869. Browne, Walter Raleigh, Managing Director, Bridgwater Engineering Works, Bridgwater.

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.

1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.

1872. Brunner, Henry, Messrs. John Hutchinson and Co.'s Alkali Works, Widnes; and Cliff House, Appleton, Widnes.

1865. Bryant, Frederick William, 6 Westminster Chambers, Victoria Street, Westminster, S.W.

1866. Bryham, William. Rose Bridge and Douglas Bank Collieries, near Wigan.

1873. Buckley, Robert Burton. Assistant Engineer, Indian Public Works Department. Deegate Lodge, Dinapore, Bengal, India : (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 23 Lower King Street, Manchester.

1872. Bullock, Thomas, Jun., Messrs. Thomas Bullock and Sons, Button Manufacturers, Cliveland Street Works, Birmingham.

1870. Burgh, Nicholas Proctor, 80 Cornhill, London, E.C.

1874. Burn, William Edward, 171 Portland Road, Newcastle-on-Tyne.

1871. Burrows, James, Douglas Bank, Wigan.

1870. Bury, William, 5 New London Street, London, E.C.

1873. Bury, William Tarleton, Messrs. Bury and Co., Regent Steel Works, Sheffield.

1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.

1859. Butler, John, Stanningley Iron Works, near Leeds.

1859. Butler, John Octavius, Kirkstall Forge, near Leeds.

1873. Butterfill, Henry Holt, 213 Regent Street, Hull.

1871. Cabry, Charles, District Resident Engineer, North Eastern Railway, York.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.

1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.

1864. Campbell, David, 105 Eglinton Street, Glasgow.

1869. Campbell, James, Hunslet Engine Works, Leeds.

1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford ; and St. Ann's, Burley, Leeds.

1875. Cardozo, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmão, Pernambuco Engine Works, Pernambuco, Brazil : (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.) (*Life Member.*)

1869. Carpmael, Frederick, 31 Berners Street, Ipswich.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C.

1868. Carrington, Thomas, Mining Engineer, Kiveton Park Collieries, near Sheffield ; and High Hazels, Darnall, near Sheffield.

1874. Carrington, William T. H., 76 Cheapside, London, E.C.

1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.

1876. Carson, William, Engineer, Wallasey Local Board, Egremont, Birkenhead.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.
1869. Caspersen, Hans William, Engineer, Danish Government Railway Service ; 164 Rye Hill, Newcastle-on-Tyne.
1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.
1871. Chamberlain, Walter, 203 Hagley Road, Edgbaston, Birmingham.
1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.
1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.
1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.
1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.
1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1869. Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.
1866. Claridge, Thomas, Newbridge Crescent, Wolverhampton.
1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan ; and Cranbury Lodge, Park Lane, Wigan.
1859. Clark, George, Southwick Engine Works, near Sunderland.
1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.
1865. Clarke, John, Messrs. Hudswell Clarke and Rogers, Railway Foundry, Jack Lane, Leeds.
1869. Clarke, William, Messrs. Clarke Watson and Gurney, Victoria Works, South Shore, Gateshead.
1859. Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead ; and D 7 Exchange Buildings, Liverpool.
1875. Clayton, Charles, Soho Foundry, Preston.
1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1871. Cleminson, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1873. Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley ; and The Grange, Stourbridge.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, 6 Westminster Chambers, Victoria Street, Westminster, S.W.
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne ; and Oakfield House, Gosforth, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1876. Coe, William John, 1 Rumford Place, Liverpool.
1847. Coke, Richard George, Mining Engineer, Tapton Grove, Chesterfield.
1867. Coke, William Langton, District Engineer, Cape Government Railways, Port Elizabeth, Algoa Bay, Cape of Good Hope : (or care of William Sacheverell Coke, Brookhill Hall, near Alfreton.)
1873. Collingham, Robert Moss, Messrs. Good Collingham and Menzies, Green Lane Foundry, Hull.
1874. Conyers, William, Engineer, Locomotive Superintendent, and General Manager, Otago Railways, Dunedin, Otago, New Zealand.
1875. Cooper, Frederick, Chief Engineer, H. M. Gun Carriage Department, Bombay.
1874. Cooper, William, Messrs. Gilbert and Cooper, Engineers and Iron Shipbuilders, Neptune Iron Works, Hull.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1875. Cotton, Francis Michael, Messrs. Field Field and Cotton, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1875. Cottrill, Robert Nivin, Beehive Works, Bolton.
1868. Coulson, William, Mining Engineer, Shamrock House, Durham.
1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.
1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.
1870. Cowen, George Roberts, Beck Foundry, Brook Street, Nottingham.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.
1876. Crampton, Willoughby, Messrs. Crampton Brothers, Central Tool Works, Sheffield ; and 37 Queen Street, Cannon Street, London, E.C.
1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.
1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes ; and Ditton Lodge, Warrington.
1869. Crossley, Louis J., Dean Clough Carpet Mills, Halifax.
1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.
1863. Crow, George, Messrs. R. Stephenson and Co.'s Works, Newcastle-on-Tyne.
1874. Curry, William, Locomotive Superintendent, Great Northern Railway of Ireland, Dublin.
1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.
1876. Cuss, Henry Berriman, Neptune Forge, Chain and Anchor Works, Tipton.
1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1866. Daniel, Edward Freer, Messrs. Thornewill and Warham's Iron Works, Burton-on-Trent; and 75 Branstone Road, Burton-on-Trent.
1866. Daniel, William, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds; and 37 Camp Road, Leeds.
1872. Danson, Thomas James, 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1865. Darby, Abraham, Treberfydd, Bwlch, Brecknockshire.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1873. Davey, Henry, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.
1874. Davis, Alfred, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.
1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.
1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1874. Davy, Walter Scott, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1874. Daw, Samuel, 5 Dock Chambers, Cardiff.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1861. Dawson, Benjamin, Engineer, Haswell Colliery, Fence Houses.
1876. Dawson, Thomas Joseph, Mining Engineer, Cocken, near Fence Houses.
1869. Day, St. John Vincent, 166 Buchanan Street, Glasgow.
1874. Deacon, George Frederick, Borough Engineer, Municipal Offices, Dale Street, Liverpool.
1874. Deakin, Thomas, Sandon Street Engine Works, Broughton Road, Salford, Manchester.
1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.
1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1872. Denton, John Punshon, Tanton Hall, Stokesley, near Northallerton.
1868. Derham, John J., Brookside, near Blackburn.
1875. Dickinson, William, Messrs. Eastons and Anderson, 65 Southwark Street, London, S.E.
1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1868. Dodman, Alfred, St. James's Iron Works, Lynn.
1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.
1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Viewfield, Stanwix, near Carlisle.
1873. Dove, George, Jun., Redbourn Hill Iron and Coal Co.'s Works, Frodingham, near Brigg.
1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Royal Exchange, Middlesbrough.
1874. Dredge, James, 37 Bedford Street, Strand, London, W.C.
1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.
1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1864. Dunn, Thomas Edward, Kurhurballee Collieries, Chord Line East Indian Railway, viâ Muddapur Junction, India; and The Cottage, Rusper, near Horsham.
1875. Durie, James, 130 Waterloo Road, Manchester.
1860. Dyson, George, Saltburn-by-the-Sea.
1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1858. Easton, Edward, Messrs. Eastons and Anderson, Grove, Southwark Street, London, S.E.; and 7 Delahay Street, Westminster, S.W.
1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.
1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.
1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.
1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham ; and Selly Oak Works, near Birmingham.
1870. Elsdon, Robert, 76 Manor Road, Upper New Cross, London, S.E.
1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.
1875. Elwell, Thomas, Jun., Engineer, Messrs. Varrall Elwell and Middleton's Works, 1 Avenue Trudaine, Paris.
1857. Evans, John Campbell, 8 Great George Street, Westminster, S.W.
1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham ; and Finstal, Bromsgrove.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.
1869. Eyth, Max, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.
1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds ; and Goldsborough Hall, Knaresborough.
1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.
1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, Avenue de la Gare, St. Ouen, France.
1867. Fardon, Thomas, Messrs. Hayward Tyler and Co.'s Works, 84 Upper Whitecross Street, London, E.C. ; and 31 Wilberforce Road, Finsbury Park, London, N.
1872. Fearn, John Wilmot, Mining Engineer, 31 Devonshire Street, Chesterfield ; and Newbold Road, Chesterfield.
1876. Fell, John Corry, 57 Metropolitan Buildings, Queen Victoria Street, London, E.C.
1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.
1870. Ferguson, Henry Tanner, District Locomotive Superintendent, Great Indian Peninsula Railway, Egutpoora, near Bombay, India.
1854. Fernie, John, Bonchurch, Ventnor, Isle of Wight.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1872. Fidler, Edward, Platt Lane Colliery, Wigan.
1867. Field, Edward, Messrs. Field Field and Cotton, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.

1868. Firth, Arthur, Leeds Iron Works, Leeds.
1868. Firth, Samuel, 16 York Place, Leeds.
1874. Firth, William, Burley Wood, Leeds.
1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.
1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Westbromwich.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)
1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1867. Fletcher, Lavington Evans, Chief Engineer, Association for the Prevention of Steam Boiler Explosions, 9 Mount Street, Albert Square, Manchester.
1872. Flower, James J. A., Messrs. James Flower and Sons, Cape Town, Cape of Good Hope; and 9 America Square, Crutched Friars, London, E.C.
1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.
1861. Forster, Edward, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham.
1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.
1861. Foster, Sampson Lloyd, 2 Prince's Place, Duke Street, St. James', London, S.W.; and Callipers Hall, Chipperfield, Rickmansworth, Herts.
1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.
1875. Fox, Samson, Leeds Forge, Leeds.
1859. Fraser, John, 18 York Place, Leeds.
1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield.
1852. Froude, William, F.R.S., Chelston Cross, Torquay.
1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.
1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., Director of Works and Public Buildings, 12 Whitehall Place, London, S.W.; and 12 Chester Street, Grosvenor Place, London, S.W.
1870. Garstang, James H., General Manager, Signal Construction Works, Monmouth Street, Bridgwater.
1867. Gauntlett, William Henry, 9 Grange Road, Middlesbrough.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.
1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.
1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.
1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.
1876. Gillett, John, Melksham Iron Works, Melksham.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.
1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.
1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.
1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden.
1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)
1871. Gowenlock, Alfred Hargreaves, care of Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta.
1869. Grainger, James Nixon, Public Works Department, Chepank, Madras: (or care of G. N. Henton, 88 Alexandra Terrace, Newport, Isle of Wight.)
1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 127 Queen's Road, Peckham, London, S.E.
1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.
1870. Gray, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.
1870. Greaves, James Henry, 2 Great George Street, Westminster, S.W.
1861. Green, Edward, Jun., Messrs. E. Green and Son, Phœnix Works, Wakefield.
1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.
1874. Greenwood, William Henry, 53 Warwick Street, Hulme, Manchester.
1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1874. Grew, Nathaniel, 8 New Broad Street, London, E.C.
1856. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1860. Grice, Frederic Groom, Ansty's Lea, Torquay.
1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1873. Griffiths, John Alfred, Messrs. Griffiths Brothers and Co., Toowoomba Foundry, Ruthven Street, Toowoomba, Queensland: (or care of Thomas Griffiths, Higher Crumpsall, Cheetham Hill, Manchester.)

1874. Griffiths, John R., Manager, Ebbw Vale Co.'s Iron Works, Pontypool.

1876. Grundy, Ralph Darling, Wigan Coal and Iron Co.'s Works, Kirkless Hall, Wigan.

1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. Hackney, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1863. Hall, Joseph, Graz Iron Works, Graz, Styria, Austria.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1871. Hall, William Silver, Abbey Works, Nuneaton.

1871. Halpin, Druitt, Victoria Graving Docks, London, E.

1870. Hamand, Arthur Samuel, Stephenson Chambers, New Street, Birmingham.

1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham; and Leicester House, Kenilworth Road, Leamington.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, São Paulo, Brazil.

1870. Hannah, Joseph Edward, New Exchange Buildings, Middlesbrough.

1874. Harding, William Bishop, care of Messrs. Robey and Co., 1 Euler Strasse, Budapest, Hungary.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1873. Harman, Harry Jones, Resident Engineer to the Duke of Sutherland, Engineer's Office, Brora, Sutherland.

1873. Harris, Richard Henry, Malvern Link, Worcestershire.

1871. Harrison, Joseph Edward, Woodside Iron Works, near Dudley.

1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.

1874. Hart, James, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1872. Hartnell, Wilson, Rodborough, Stroud, Gloucestershire.

1871. Hartness, John, Lloyd's Inspector, Wear Chain and Anchor Testing Works, Sunderland.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.
1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1873. Headly, Lawrance, 8 Newnham Terrace, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, 9 Rumford Place, Liverpool.
1864. Heathfield, Richard, Lion Galvanising Works, Wiggin Street, Icknield Port Road, Birmingham.
1875. Heenan, Richard Hammersley, Executive Engineer, Public Works Department, Bhawulpoor, viâ Mooltan, Punjaub, India: (or care of Walter May, Suffolk Works, Berkley Street, Birmingham.)
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.
1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.
1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, 2 Green Bank, Moss Lane East, Manchester.
1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.
1872. Hewlett, Alfred, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.
1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.
1870. Higson, John, Mining Engineer, St. George's Chambers, Albert Square, Manchester.
1873. Hildebrandt, John Albert Reinhold, Bow Chambers, 55 Cross Street, Manchester.
1871. Hill, Alfred C., Royal Exchange, Middlesbrough; and Newcomen Street, Coatham, Redcar.
1867. Hill, Henry Walker, 51 Hampden Street, Nottingham.
1873. Hilton, Franklin, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.

1869. Hind, Henry, Central Engineering Tool Works, Queen's Road, Nottingham.

1876. Hind, Thomas William, Messrs. Henry Hind and Son., Central Engineering Tool Works, Queen's Road, Nottingham.

1874. Hird, Holmes, Engineer, Messrs. Bass and Co.'s Brewery, Burton-on-Trent.

1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.

1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.

1852. Holcroft, James, Norton, near Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1871. Holiday, Joseph, Union Foundry, Cutler Heights, near Bradford.

1865. Holliday, John, Meyrick House, Hill Top, Westbromwich.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, Royal Insurance Buildings, Leeds.

1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.

1867. Homer, Charles James, Mining Engineer, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1874. Hopkinson, John, Jun., D.Sc., Manager, Lighthouse and Optical Department, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham.

1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 46 Queen Street, Edinburgh.)

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, King's Newton, near Derby.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury,

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.

1875. Hosgood, Thomas Hopkin, Troedyrhiew, Merthyr Tydvil.

1873. Hoskin, Richard, 2 Alliance Chambers, George Street, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.

1861. Howell, Joseph Bennett, Brook Steel Works, Brookhill, Sheffield.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1873. Hughes, Henry, Falcon Iron Works, Loughborough.

1871. Hughes, Joseph, Parton Hæmatite Iron Works, near Whitehaven.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, care of H. R. Hunt, Superintendent of Locomotive and Permanent Way Department, Douglas, Isle-of-Man.

1874. Hunt, William, Jun., Messrs. William Hunt and Sons, Alkali Works, Lea Brook, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1864. Hutchinson, Edward, Stotely, Haslemere, Surrey.

1865. Hyde, Colonel Henry, R.E., India Office, Westminster, S.W. (*Life Member.*)

1867. Inglis, William, Soho Iron Works, Bolton.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and D 7 Exchange Buildings, Liverpool.

1866. Ireland, William, care of Jonathan Ireland, Edward Street, Broughton Lane, Manchester.

1872. Jack, Alexander, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1876. Jackson, Henry James, Superintending Engineer, General Steam Navigation Co.'s Works, Deptford, London, S.E.

1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.

1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1873. Jackson, Samuel, Assistant Locomotive Superintendent, Great Indian Peninsula Railway, Byculla, Bombay: (or care of W. Albert Jackson, 1 Mulberry Street, Sheffield.)

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, Windsor Iron Works, Garston, near Liverpool.
1876. Jacobs, Charles Mattathias, Post Office Chambers, Bute Docks, Cardiff.
1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.
1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.
1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford.
1876. Jemson, James, Engineer to the Kay Shuttleworth Mineral Estate, Gawthorpe Hall, near Burnley.
1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.
1861. Jessop, Thomas, Messrs. William Jessop and Sons, Park and Brightside Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Hydraulic Engineering Works, Chester.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.
1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.
1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.
1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.
1873. Jones, Edward, Drayton House, Trinity Road, Birchfield, Birmingham.
1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.
1867. Jones, George Edward, care of Messrs. James Nicol Fleming and Co., Calcutta: (or care of Edward Jones, Wylde Green, near Birmingham).
1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.
1872. Jones, William Richard Sumption, Executive Engineer, Workshops Division, Lower Ganges Canal, Narora, viâ Aligarh, India: (or care of J. H. S. Jones, Garth Villa, Bassaleg, near Newport, Monmouthshire).

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1869. Keep, Alfred, Metal Sheathing Works, 10 Coleshill Street, Birmingham.
1867. Kellett, John, 27 King Street, Wigan.
1873. Kelson, Frederick Colthurst, 6 Marine Terrace, Waterloo, Liverpool.

1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.
1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.
1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.
1866. Kershaw, John, 9 Great Queen Street, Westminster, S.W.
1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.
1870. Kinsey, Henry, Postern Buildings, Swansea.
1872. Kirk, Alexander Carnegie, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.
1875. Kirkwood, James, Chief Engineer, Revenue Steamer "Fei-Hu," Hong Kong, China: (or care of F. Degenaer, Hong Kong.)
1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.
1874. Klein, Thorvald, Works Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.
1863. Lancaster, John, Bilton Grange, Rugby.
1870. Lancaster, Joshua, Darwen Iron Works, Darwen; and 4 Leaf Square, Pendleton, Manchester.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1874. Laws, William George, Central Buildings, 18 Grainger Street West, Newcastle-on-Tyne.
1870. Layborn, Daniel, Messrs. Gladstone and Wyllie's Cotton Rice and Oil Factories, Rangoon, Burmah, India: (or care of Daniel Layborn, Sen., Beverley.)
1856. Laybourne, Richard, Rhymney Iron Works, Rhymney, Monmouthshire.
1860. Lea, Henry, 35 Paradise Street, Birmingham.

1865. Ledger, Joseph, Keswick.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton.
1874. Lees, James, Long Island Iron Works, Carlisle.
1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Town Hall Buildings, Manchester.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.
1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.
1872. Leslie, Bradford, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons' Tyne Hæmatite Iron Works, Scotswood-on-Tyne.
1872. Lewis, Rowland Watkin, Britannia Boiler Tube Works, Ettingshall, Wolverhampton.
1860. Lewis, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Linsley, Samuel W., Engineer, Whitburn Colliery, near Sunderland.
1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.
1866. Little, George, Messrs. Platt Brothers and Co.'s, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1873. Llewellyn, William Hely, Messrs. Llewellyn and Cubitt, Rhondda Engine Works, Pentre, Rhondda Valley, Pontypridd.
1867. Lloyd, Charles, Glebe Buildings, Stoke-upon-Trent.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1871. Lloyd, Francis Henry, Darlaston Steel and Iron Works, near Wednesbury; and Wood Green, Wednesbury.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1864. Lloyd, Sampson Zachary, Darlaston Steel and Iron Works, Wednesbury; and Arcley Hall, Stourport.
1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.
1862. Lloyd, Wilson, Myvod House, Wood Green, Wednesbury.
1863. Loam, Matthew Hill, Gas and Water Engineer, Ivy House, Colwich Road, Nottingham.
1869. Lockhart, Humphrey Campbell, Messrs. Pilkington Brothers' Plate Glass Works, St. Helen's.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.
1856. Longridge, Robert Bewick, Chief Engineer, Steam Boiler Insurance Company, 67 King Street, Manchester.
1875. Longridge, Robert Charles, Assistant Manager, Steam Boiler Insurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Boyne Grove, Maidenhead.
1861. Low, George, Bishop's Hill Cottage, Ipswich.
1873. Lowe, John Edgar, 2 Laurence Pountney Hill, London, E.C.
1873. Lucas, Arthur, 23 Delahay Street, Westminster, S.W.
1872. Lukin, Augustus Stephen, Newbold Road, Chesterfield: (or care of Rev. E. Banks, Coleshill Vicarage, Highworth, near Swindon.)
1854. Lynde, James Gascoigne, City Hall, Manchester.
1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1864. Macfarlane, Walter, Saracen Foundry, Washington Street, Glasgow.
1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka; and Oriental Bank Corporation, Kobe, Japan: (or care of Dr. Maclagan, 136 Nethergate, Dundee.)
1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan.
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.
1873. Mair, John George, Manager, Messrs. Simpson and Co.'s Engine Works, Grosvenor Road, Pimlico, London, S.W.
1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.
1862. Mansell, Richard Christopher, Mechanical Engineer, South Eastern Railway, Ashford.
1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.
1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.
1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1871. Marsh, Henry William, Winterbourne, near Bristol.
1875. Marshall, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E; and Laurel Bank, Prospect Hill, Walthamstow, Essex. (*Life Member.*)
1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1862. Marshall, James, 111 Hill Street, Rhymney, Monmouthshire.

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.
1859. Marshall, William Ebenezer, 1 Beech Grove Terrace, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.
1853. Marten, Henry John, Parkfield House, near Wolverhampton.
1867. Martin, William, 13 Avenue de la Reine Hortense, Paris.
1857. Martindale, Lt.-Colonel Ben Hay, C.B., R.E., General Manager, London and St. Katharine Docks, Dock House, 109 Leadenhall Street, London, E.C.
1854. Martineau, Francis Edgar, Globe Works, 278 New Town Row, Birmingham.
1876. Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.
1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1875. Matthews, James, 2 Lion Chambers, Broad Street, Bristol.
1875. Matthews, Thomas William, Messrs. Leather Matthews and Co., Broughton Road Iron Works, Salford, Manchester.
1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil : (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)
1853. Maudslay, Henry, care of John Barnard, 8 Lancaster Place, Strand, London, W.C. (*Life Member.*)
1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.
1873. Maw, William Henry, 37 Bedford Street, Strand, London, W.C.
1869. May, George, Mining Engineer, Harton Collieries, Tyne Docks, South Shields.
1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.
1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, Churton Lodge, Churton, near Chester.
1859. Maylor, William, care of Messrs. Stanes Watson and Co., 4 Cullum Street, Fenchurch Street, London, E.C.
1874. McClean, Frank, 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1867. McEwen, James, Messrs. Firmstone and McEwen, Lays Iron Foundry, near Stourbridge.

1864. McEwen, Lawrence Thompson, Lombard House, George Yard, Lombard Street, London, E.C.

1868. McKay, Benjamin, Steel Company of Canada, Londonderry, Nova Scotia.

1872. McNeile, Alexander, Messrs. McNeile Brothers, Wheel and Axle Works, 26 John Street, Pentonville Road, London, N.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1858. Meik, Thomas, Messrs. Meik and Nisbet, 6 York Place, Edinburgh.

1857. Menelaus, William, Dowlais Iron Works, Dowlais.

1876. Menzies, William, Messrs. Menzies and Blagburn, King Street, Newcastle-on-Tyne.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire Engine Works, 63 Long Acre, London, W.C.

1867. Merryweather, Richard M., Messrs. Merryweather and Sons, Fire Engine Works, 63 Long Acre, London, W.C.

1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1856. Mitchell, Charles, Iron Shipbuilding Yard, LowWalker, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Eastons and Anderson's, Erith Iron Works, Erith, London, S.E.

1872. Moon, Richard, Jun., Mersey Steel and Iron Works, Caryl Street, Liverpool.

1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1872. Moorsom, Warren Maude, London and North Western Railway, Locomotive Department, Crewe.

1867. Morgans, Thomas, The Guildhall, Bristol.

1874. Morris, Edmund Legh, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1868. Morris, William, Waldridge Colliery, Chester-le-Street.

1873. Morrison, Henry Martin, 15 Birch Lane, Longsight, Manchester.

1865. Mosse, James Robert, Public Works Office, Colombo, Ceylon.

1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, Engineer, Rochdale Canal Navigation, Rochdale.

1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.

1876. Muirhead, Richard, Hamond Place, Chatham.

1872. Mulliner, Charles, 29 Blackfriars, Manchester.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1876. Naish, William Prideaux, Messrs. Naish and Osborn's, Birmingham Iron Foundry, 20 Coleshill Street, Birmingham.
1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.
1848. Napier, John, Messrs. Robert Napier and Sons, Engineers and Shipbuilders, Lancefield House, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.
1869. Nelson, James, King's House Engine Works and Foundry, Sunderland.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, 2 The Pavement, Clapham Common, London, S.W. (*Life Member.*)
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1876. Newton, William Manfield, Messrs. John Brierly and Sons', Railway Signal Engineers, 66 Chancery Lane, London, W.C.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.
1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.
1870. Nye, Henry, Messrs. Varrall Elwell and Middleton's Works, 1 Avenue Trudaine, Paris.

1868. O'Connor, Charles, Messrs. John Elder and Co.'s, Fairfield Engine Works, Govan, Glasgow.
1875. Okes, John Charles Raymond, Manager, Messrs. Hayward Tyler and Co.'s Steam Pump Works, 84 Upper Whitecross Street, London, E.C.
1866. Oliver, William, Victoria and Broad Oaks Foundries, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1870. Osman, Joseph, Bey, Chief Engineer and Superintendent of Factories to the Khedive of Egypt, Boulac, Cairo; and St. James's Hotel, 77 Piccadilly, London, W.

1867. Oughterson, George Blake, Messrs. Manlove Alliott and Co., 45 Rue d'Elbeuf, Rouen, France.

1847. Owen, William, Wheathill Foundry, Rotherham; and Clifton House, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.

1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.

1871. Parke, Frederick, Withnell Fire Clay Works and Cotton Mill, near Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India.

1873. Pearce, Richard, Deputy Carriage Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India.

1848. Pearson, John, 15 Old Hall Street, Liverpool; and Golborne Park, near Newton-le-Willows, Lancashire.

1869. Pearson, William Hall, 50 Ann Street, Birmingham.

1866. Peele, Arthur John, Oakley House, Bellevue, Shrewsbury.

1848. Penn, John, F.R.S., The Cedars, Lee, London, S.E. (*Life Member.*)

1873. Penn, John, Jun., Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Percy, Cornelius McLeod, Wigan Coal and Iron Co.'s Works, Kirkless Hall, Wigan.

1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1867. Pidgeon, Daniel, Holmwood, Putney Hill, London, S.W.
1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham.
1876. Pinel, Charles Louis, 26 Rue Meridienne, Rouen, France.
1875. Platt, Edward, Messrs. Ackroyd and Platt, Albert Iron Works, Sowerby Bridge.
1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1869. Player, John, Clydach Foundry, near Swansea.
1866. Plum, Thomas Edward Day, Standard Iron and Steel Works, Gorton, near Manchester.
1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.
1872. Pole, William, F.R.S., 31 Parliament Street, Westminster, S.W.
1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Smith, Longclose Works, Newtown, Leeds.
1876. Pooley, Henry, Jun., Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.
1860. Ponsonby, Edward Vincent, 1 Torquay Villa, Maindee, Newport, Monmouthshire.
1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.
1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.
1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.
1870. Powell, Thomas, (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.
1874. Powell, Thomas, (Nephew), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.
1867. Powell, William, Harbour Works, Douglas, Isle of Man.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1856. Preston, Francis, Turnbridge Iron Works and Forge, Huddersfield.
1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and Rose Villa, Gateshead Road, Jarrow.
1875. Prior, Johannes Andreas, Sub-Director, Messrs. Burmeister and Wain's Engineering and Shipbuilding Works, Copenhagen.
1874. Prosser, William Henry, Messrs. Harfield and Co.'s, Mansion House Buildings, Queen Victoria Street, London, E.C.

1875. Provis, George Stanton, District Locomotive Superintendent, East Indian Railway, Assensole, India: (or care of T. J. Provis, The Grange, Ellesmere, near Shrewsbury.)

1866. Putnam, William, Darlington Forge, Darlington.

1873. Radcliffe, Arthur Henry Wright, 7 Union Street, Birmingham.

1870. Radcliffe, William, Moorgate, Rotherham.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1875. Rainford, Arthur, Manager, Messrs. Jessop and Co., Phœnix Foundry, Calcutta.

1864. Ramage, Robert, The Hollies, Sea Bank Road, North Egremont, near Birkenhead.

1847. Ramsbottom, John, Harewood Lodge, Mottram, near Manchester.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.

1860. Ransome, Allen, Jun., 304 King's Road, Chelsea, London, S.W.

1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Ratliffe, George, Mersey Steel and Iron Co.'s Works, Caryl Street, Liverpool.

1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.

1872. Rawlins, John, Manager, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.

1870. Reed, Edward James, C.B., M.P., Broadway Chambers, Westminster, S.W.

1859. Rennie, George Banks, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1876. Restler, James William, Assistant Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1875. Rich, William Edmund, Engineer, Messrs. Eastons and Anderson, 65 Southwark Street, London, S.E.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1863. Richardson, The Hon. Edward, Minister of Public Works, Wellington, New Zealand.
1865. Richardson, John, Methley Park, near Leeds.
1873. Richardson, John, Engineer to Messrs. Robey and Co., Perseverance Iron Works, Lincoln.
1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.
1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.
1863. Rigby, Samuel, Messrs. Armitage and Rigbys, Cock Hedge Mill, Warrington.
1871. Rigg, John, Deputy Locomotive Superintendent, London and North Western Railway, Crewe.
1874. Riley, James, Manager, Landore Siemens-Steel Works, Landore, Swansea.
1873. Robertson, George, 9 Fenchurch Street, London, E.C.
1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.; and Palé, Corwen.
1873. Robey, Robert, Jun., Trent Mining Co., Thrumpton, Keyworth, near Nottingham.
1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.
1865. Robinson, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1872. Rofe, Henry, Resident Engineer, Nottingham Water Works, Nottingham; and 111 Forest Road West, Nottingham.
1868. Rogers, William, care of J. Kenyon Rogers, 7 Tower Chambers, Liverpool.
1871. Rollo, David, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1853. Ronayne, Joseph Philip, M.P., Rinn Ronain, Queenstown, Ireland.
1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.
1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.
1874. Ross, John Alexander George, 34 Collingwood Street, Newcastle-on-Tyne.
1876. Ross, Thomas Braban, Sheepbridge Coal and Iron Works, Chesterfield.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.
1860. Rumble, Thomas William, Chief Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E. (*Life Member.*)
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 26 Parliament Street, Westminster, S.W.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople : (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1859. Salt, George, Sir Titus Salt Bart., Sons and Co., Saltaire, near Bradford.
1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury ; and 56 Prince's Gate, South Kensington, London, S.W.
1871. Sanders, Richard David, Manager, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1861. Sanderson, George Grant, Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.
1864. Sanderson, John, Weardale and Shildon District Water Works, Tunstall Reservoir, Wolsingham, near Darlington.
1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.
1875. Saxon, George, Spring Works, Openshaw, Manchester.
1869. Scarlett, James, 14 St. Ann's Square, Manchester.
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1876. Scott, David, Engineer to the Port Trust Commissioners, Calcutta.
1875. Scott, Frederick Whitaker, Messrs. Scott Brothers' Wire and Hemp Rope Works, West Gorton, Manchester.
1868. Scott, George Lamb, 46 Lancaster Avenue, Fennel Street, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius : (or care of James H. Murray, 14 Marquis Road, Finsbury Park, London, N.)
1868. Scriven, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.
1864. Seddon, John, 98 Wallgate, Wigan.
1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1867. Selby, Millin, care of Atherton T. Selby, Atherton Old Hall, Leigh, near Manchester.
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.
1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contractors, 7 Hastings Street, Calcutta.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Co.'s Works, Birmingham.
1867. Sharpe, Charles James, Stowe House, London Road, Twickenham.
1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 110 Cannon Street, London, E.C.
1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.
1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.
1872. Shirley, Henry Lionel, Engineer, Constantinovskoi Railway, South Russia; and 9 Queen's Gate Terrace, London, S.W.
1872. Shoolbred, James Nelson, 3 Westminster Chambers, Victoria Street, Westminster, S.W.
1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1851. Siemens, Charles William, D.C.L., F.R.S., 12 Queen Anne's Gate, Westminster, S.W.; and 3 Palace Houses, Bayswater Road, London, W.
1871. Simon, Henry, 7 St. Peter's Square, Manchester.
1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 35 Commercial Road, Pimlico, London, S.W.
1847. Sinclair, Robert, Goodrington House, Paignton, South Devon.
1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.
1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, 4 Clifton Park, Clifton, Bristol.
1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.
1876. Smethurst, William, Messrs. Dewhurst Hoyle and Smethurst, Garswood Hall Colliery, Ashton, near Wigan.
1873. Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.
1866. Smith, Edward Fisher, The Priory Offices, Dudley.
1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1876. Smith, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness.

1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.

1857. Smith, William, 18 Salisbury Street, Strand, London, W.C.

1866. Smith, William, Messrs. A. and W. Smith and Co., Eglinton Engine Works, Glasgow.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1859. Sokoloff, General Alexander. Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Henry Tottie, 5 Great Winchester Street Buildings, London, E.C.)

1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.

1865. Sparrow, William Mander. Osier Bed Iron Works, Wolverhampton.

1876. Speck, Thomas Samuel, Resident Engineer and Locomotive Superintendent, Metropolitan District Railway, Lillie Bridge Works, West Brompton, London, S.W.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

1853. Spencer, Thomas, Blackladies, Penkridge, near Stafford.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.

1876. Spriggs, Christopher, 110 Everton Road, Manchester.

1862. Stableford, William, Railway Carriage Works, Oldbury, near Birmingham.

1869. Stabler, James, Messrs. Shand Mason and Co., Fire Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.

1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.

1874. Steel, Thomas Dyne, Bank Chambers, Newport, Monmouthshire.

1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.

1876. Sterne, Louis, Messrs. Thomson Sterne and Co., Crown Iron Works, Glasgow; and 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and 92 Lancaster Gate, Hyde Park Gardens, London, W.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1875. Stoker, Frederick William, Manager, Messrs. Shaw Johnson and Reay, The Moor Iron Works, Stockton-on-Tees.
1864. Stokes, James Folliott, Longview, Simla, India.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Rossetta Villa, Avenue Road, Southampton.
1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.
1873. Strype, William George, Manager, Custom-House Flour Mill, Store Street, Dublin; and 2 Sydenham Road, Dundrum, near Dublin.
1861. Sumner, William, 2 Brazennose Street, Manchester.
1875. Sutcliffe, Frederic John Ramsbottom, Manager of Engineering Department, Bowling Iron Works, near Bradford.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley; and Oldswinford, near Stourbridge.
1864. Swindell, James Swindell Evers, Clent House, Stourbridge.
1872. Symington, William Weldon, Bowden Steam Mills, Market Harborough.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham.
1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham; and Aviary Cottage, Illogan, near Redruth.
1859. Tannett, Thomas, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.
1873. Taylor, Charles Dyke, Mining Engineer, Cape Copper Mines; care of J. C. Leaver, 6 Queen Street Place, Upper Thames Street, London, E.C.
1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.
1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.
1874. Taylor, Percyvale, Panther Lead Smelting Works, St. Philip's, Bristol.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1876. Taylor, William Henry Osborne, Panteg Steel and Engineering Works, Panteg, near Pontypool.
1872. Teague, William, Mining Engineer, Tincroft Mines, Redruth.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.
1864. Thomas, Thomas, 19 The Parade, Cardiff.
1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.
1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1875. Thoms, George Eastlake, Engineer, Local Board Offices, Great Crosby, Liverpool.
1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.
1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.
1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.
1875. Thwaites, William Henry, Messrs. Thwaites and Carbutt's, Vulcan Iron Works, Thornton Road, Bradford.
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1873. Tomkins, Edward, Montpelier Place, Fairfield, Buxton.
1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co.'s, Atlas Works, Manchester.
1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1876. Trevithick, Richard Francis, Locomotive Engineer, Central Argentine Railway, Rosario, Argentine Republic: (or care of F. Trevithick, The Cliff, Penzance.)

1865. Trow, John James, Messrs. William Trow and Sons, Union Foundry, Wednesbury.
1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Holyhead Road, Wednesbury.
1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.
1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham.
1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.
1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.
1874. Twibill, Joseph, Engineer and Ironfounder, Barrack Street, Tatton Street, Chester Road, Manchester.
1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1875. Unsworth, Thomas, Leicester Works, Dutton Street, Strangeways, Manchester.
1862. Upward, Alfred, 8 Queen Anne's Gate, Westminster, S.W.
1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of John Maclachlan, 15 Hamilton Street, Greenock.)
1872. Usher, Thomas, Messrs. Reay and Usher, South Hylton Iron Works, Sunderland.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1875. Wailes, John William, Landore Siemens-Steel Works, Landore, Swansea.
1865. Wainwright, William, West Central Wagon Works, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1873. Waldenström, Eric Hugo, Manager, Broughton Copper Co.'s Works, Broughton Road, Manchester.
1872. Walker, Alexander, Locomotive Superintendent, Cambrian Railways, Oswestry.
1870. Walker, Alfred, Albion Iron Works, Aldwark, York.
1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1864. Walker, Bernard Peard, Eagle Foundry, Broad Street, Birmingham.

1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, Oxford Street, Birmingham.

1875. Walker, William, Mining Engineer, Saltburn-by-the-Sea.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1865. Waller, George Arthur, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1874. Wass, John William, 21 Collingwood Street, Newcastle-on-Tyne.

1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.

1862. Watkins, Richard, Messrs. Jackson and Watkins, Canal Iron Works, Poplar, London, E.

1866. Watson, Robert, Engineer, Brereton and Hayes Collieries, near Rugeley.

1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1872. Welch, Edward John Cowling, Stephenson Boiler and Forge Co., Failsworth, Manchester.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1876. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, 13A Exchange Buildings, Liverpool.

1871. West, Henry Joseph, Messrs. Siebe West and Co., Mason Street, Westminster Bridge Road, Lambeth, London, S.E.

1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.
1862. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.
1867. Weston, Thomas Aldridge, care of The Yale Lock Manufacturing Company, Stamford, Connecticut, United States: (or care of William T. Watts, 81 Parade, Birmingham.)
1874. Whalley, Arthur John, Prince's Street, Truro.
1867. Wheatley, Thomas, Manager, Wigtownshire Railway, Wigtown, Wigtownshire.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and 16 Waterloo Road South, Wolverhampton.
1872. Whieldon, William, Messrs. Whieldon and Cooke, Collinge Engineering Works, 190 Westminster Bridge Road, Lambeth, London, S.E.
1874. White, Henry Watkins, 1 Camden Houses, Forton, Gosport.
1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)
1868. Whitehead, Peter Ormerod, The Elms, 26 Seedley Road, Pendleton, Manchester.
1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.
1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.
1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.
1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.
1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and The Firs, Fallowfield, Manchester.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford.
1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.
1867. Wilkes, John, Bordesley Tube Mills, Liverpool Street, Birmingham.
1868. Wilkieson, Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 23 Cornhill, London, E.C.
1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.
1865. Williams, Edward, Cleveland Lodge, Middlesbrough.
1872. Williams, Sir Frederick Martin, Bart., M.P., Perran Foundry, Goonvrea, Perranarworthal, Cornwall. (*Life Member.*)
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, 9 Great George Street, Westminster, S.W.
1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.

1873. Williams, William Lawrence, Manager, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.
1870. Willman, Charles, 3 Cleveland Terrace, Middlesbrough.
1872. Wilson, Alfred, Messrs. Howson and Wilson, 2 Exchange Place, Middlesbrough.
1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.
1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1863. Wilson, John Charles, Avonside Engine Works, St. Philip's, Bristol.
1857. Wilson, Robert, F.R.S.E., Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1872. Wilson, Stephen, Engineer, Wearmouth Colliery, Sunderland.
1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.
1867. Winby, Frederick Charles, Lanelay Hall, near Cardiff.
1872. Winn, Charles William, 30 Easy Row, Birmingham.
1872. Winstanley, Robert, Jun., Mining Engineer, Lancaster Avenue, Fennel Street, Manchester.
1859. Winter, Thomas Bradbury, 53 Moorgate Street, London, E.C.
1872. Wise, William Lloyd, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1872. Withinshaw, John, Birmingham Engine Works, Wiggin Street, Icknield Port Road, Birmingham.
1871. Withy, Edward, Messrs. Withy and Co., Middleton Iron Shipbuilding Yard, Hartlepool.
1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.
1876. Wood, Thomas, Mining Engineer, North Hetton Collieries, Fence Houses.
1873. Woodhead, John Proctor, 16 Tib Lane, Manchester.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1874. Worsdell, Thomas William, London and North Western Railway, Locomotive Department, Crewe.
1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.
1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place, Oxford Road, Manchester.
1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.
1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.
1876. Wright, James, Messrs. Ashmore and While's, Hope Iron Works, Bowersfield, Stockton-on-Tees.

1867. Wright, John Roper, Panteg Steel and Engineering Works, Panteg, near Pontypool.
1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.
1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1871. Wright, William, Lostwithiel.
1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.
1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1873. Young, Charles Frederic Trelawny, 112 St. Donatt's Road, New Cross, London, S.E.
1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.
1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin; and 4 The Hill, Monkstown, near Dublin.
1867. Morin, General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1873. Barry, William Henry, 7 Birchin Lane, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1873. Freeman, William George, Messrs. John Freeman and Sons, Granite Works, Penryn, Cornwall.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1874. Hardcastle, Robert Anthony, Clarence Iron Works, Leeds.

1874. Hurman, James, Traffic Superintendent, Taff Vale Railway, Cardiff; and 22 Albert Terrace, Charles Street, Cardiff.
1875. Knight, John Henry, Weybourne House, Farnham.
1858. Lawton, Benjamin C., Corbridge, Northumberland.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 2 Crown Buildings, Queen Victoria Street, London, E.C.
1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1871. Patterson, John, Liverpool and Manchester District Bank, Spring Gardens, Manchester; and Craigdarragh, Belfast.
1874. Pepper, Joseph Ellershaw, Monkbridge Iron Works, Leeds.
1856. Pettifor, Joseph, Midland Railway, Derby.
1875. Schofield, Christopher J., Clayton, near Manchester.
1859. Sherriff, Alexander Clunes, M.P., 10 Dean's Yard, Westminster, S.W.; and Craycombe House, near Pershore.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1869. Varley, John, Farnley Iron Works, Leeds.
1875. Wasalekar, Nanaji Narayan, care of Dr. Atmaram Pandurang, Candewadi, Bombay.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)

GRADUATES.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)
1872. Armstrong, Thomas, Carriage Department, Great Western Railway, Swindon.
1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.
1869. Blake, Frederick William, 23 Masshouse Lane, Birmingham.
1874. Browne, Tomyns Reginald, Messrs. Neilson and Co.'s Hyde Park Locomotive Works, Glasgow.
1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Haswell Colliery, Fence Houses.
1875. Deacon, Francis Henry, 15 Sweeting Street, Liverpool.
1873. Dobson, Richard Joseph Caistor, Sugar Fabric Trankil, Pattie, Japara, Java : (or care of R. C. Lowndes, Rice House, West Derby, Liverpool.)
1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street, Summer Lane, Birmingham.
1873. Edmunds, John Sharp Wilbraham, Elmsdale, Carpenter Road, Edgbaston, Birmingham.
1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.
1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1874. Hedley, Henry, 71 Nelson Terrace, Dorset Street, Hulme, Manchester.
1874. Hedley, Thomas, 3 Elm Vale, Fairfield, Liverpool.
1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Sheaf Works, Sheffield.
1867. Mayhew, Horace, Mining Engineer, Hindley House, near Wigan.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Lanelay Colliery, Llantrissant, Glamorganshire.
1872. Napier, Robert Twentyman, Messrs. John Penn and Sons' Marine Engine Works, Greenwich, S.E.
1876. Owen, George Charles Mickleburgh, Messrs. Sharp Stewart and Co.'s, Atlas Works, Manchester.
1867. Pearson, John Edward, Golborne Park, near Newton-le-Willows, Lancashire.
1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.
1874. Rankeilor, William Collis, Wednesbury Oak Iron Works, Tipton.
1875. Sheppard, Herbert Gurney, Messrs. James Watt and Co.'s Works, Soho Foundry, near Birmingham.
1873. Simpson, Alfred, Denmark House, Alexandra Road, St. John's Wood, near Hull.
1874. Stephenson, Joseph, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.
1874. Taylor, Arthur, Pontgibaud Lead Works, Puy de Dôme, France ; and 6 Queen Street Place, Upper Thames Street, London, E.C.
1875. Walker, Arthur Henry, Guild Hall Chambers, Cardiff.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.

DAL BRIDGE ERECTION.

Fig. 1. *Elevation.*

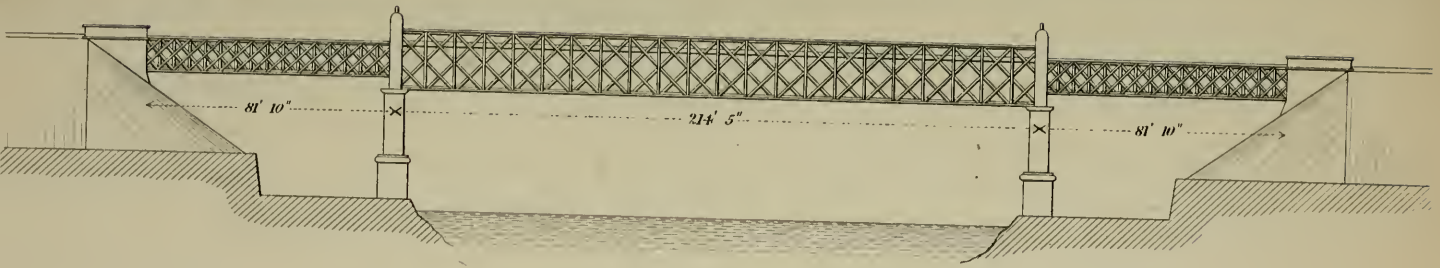
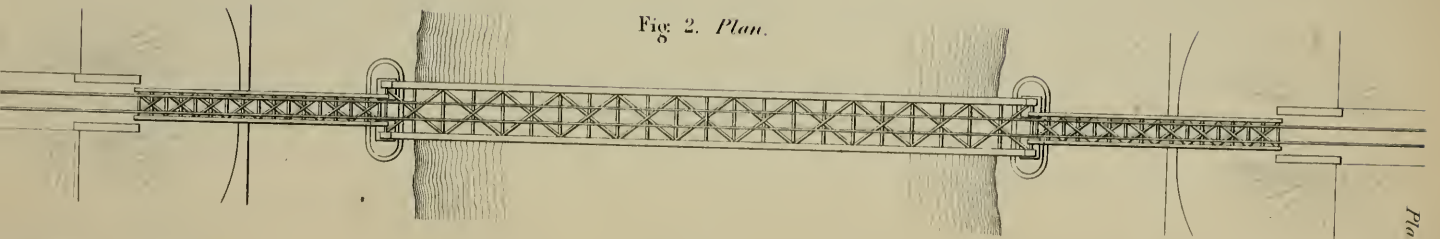


Fig. 2. *Plan.*



(Proceedings Inst. M. E. 1876.)

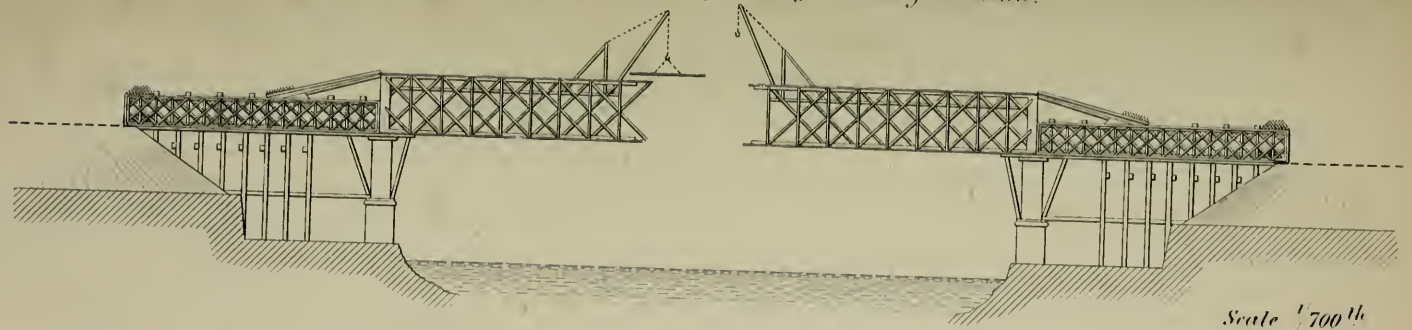
Scale 1/700 th

10 0 50 100 150 200 Feet.

Plate 1.

DAL BRIDGE ERECTION.

Fig. 3. *Elevation showing Bridge during Erection.*



Scale 1/700th

Diagram of Counterbalance for Half Span of Main Girders.

Fig. 4. *Elevation.*

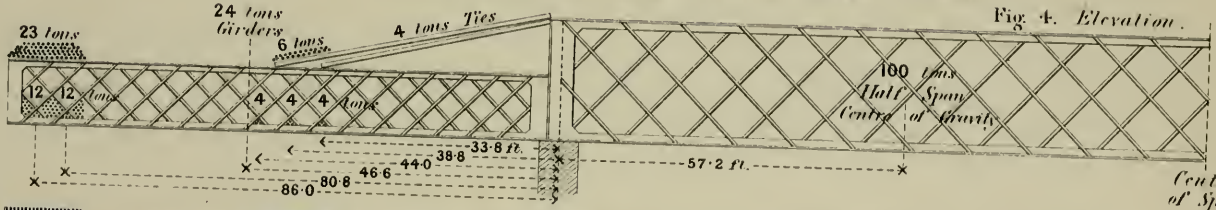
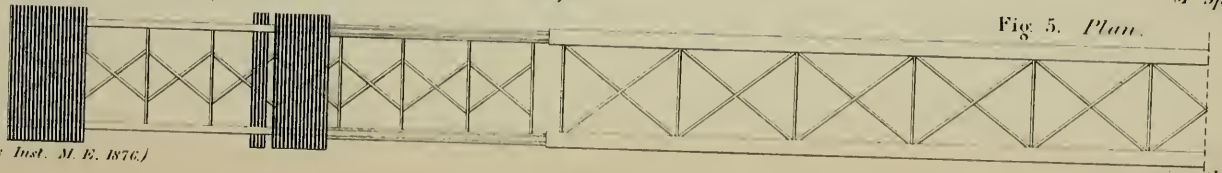


Fig. 5. *Plan.*



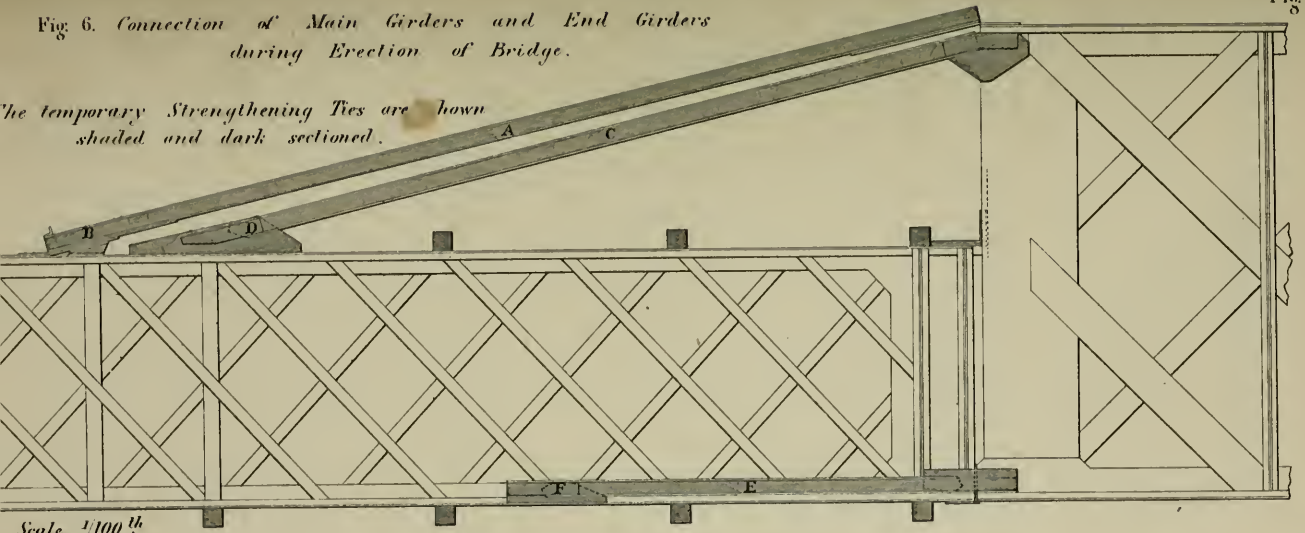
Scale 1/350th

(*Proceedings Inst. M. E. 1876.*)

Plate 2.

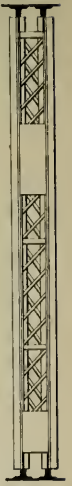
Fig. 6. *Connection of Main Girders and End Girders during Erection of Bridge.*

The temporary Strengthening Ties are shown shaded and dark sectioned.



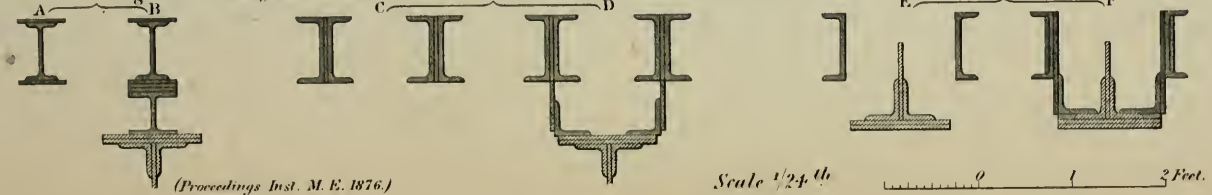
Scale 1/100 th

Fig. 8. *Main Girder.*



Section at end.

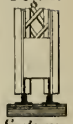
Fig. 7. *Enlarged Sections of temporary Strengthening Ties.*



Scale 1/24 th

0 1 2 Feet.

Fig. 9.

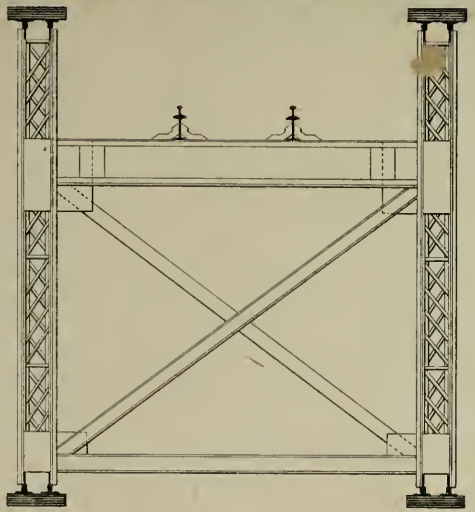


Section at Centre.

(Proceedings Inst. M. E. 1876.)

Fig. 10.

Transverse Section of Main Girders.



Scale 1/100th

0 5 10 15 20 Feet.

Fig. 11.

Transverse Section of End Girders.

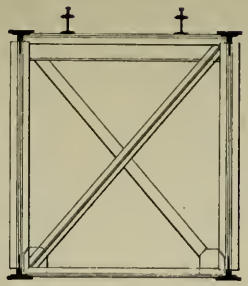


Fig. 12. *Fixed Bearing for Main Girders.*

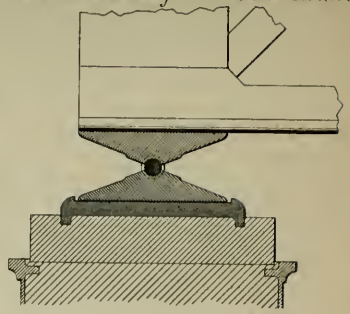
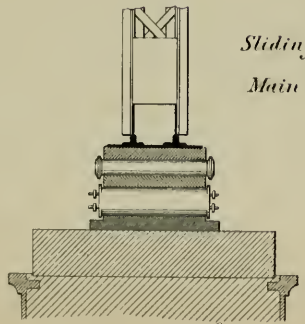
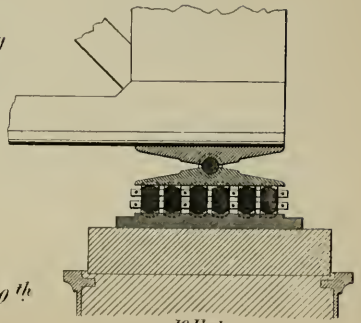


Fig. 13.



Sliding Bearing for Main Girders.

Fig. 14.



Scale 1/60th

0 5 10 Feet.

(Proceedings Inst. M. E. 1876.)

Plate 4.

PROCEEDINGS.

JANUARY 1876.

The TWENTY-NINTH ANNIVERSARY MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 27th January, 1876; FREDERICK J. BRAMWELL, Esq., F.R.S., Retiring President, in the Chair, succeeded by THOMAS HAWKSLEY, Esq., President elected at this Meeting.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1876.

The Council now beg to lay their Annual Report before the Meeting on this occasion of the Twenty-ninth Anniversary of the Institution.

The roll of the Institution shows that at the end of the last year 1875 there were

Members	Hon. Life Members	Associates	Graduates	Total
949	3	32	34	1018

as compared with

Members	Hon. Life Members	Associates	Graduates	Total
927	4	28	33	992

at the corresponding period of the previous year, showing an effective increase of 26. This increase arises as follows.

There have been elected

Members	Associates	Graduates	Total
73	4	4	81

there have been lost by death

Members	Hon. Life Member	Graduate	Total
20	1	1	22

and by resignations or by removal from the register

Members	Associates	Graduates	Total
33	0	0	33

so that while the gain from elections has amounted to 81, there must be deducted from this the loss of 55 arising from the causes above stated, leaving the net increase of 26 before mentioned.

With respect to the Financial position, the appended Balance Sheet will show that, including a balance of £10,343 12*s.* 3*d.* from the previous year, there has been a total credit of £13,814 6*s.* 9*d.*; and that the expenses have been £2636 4*s.* 2*d.*, leaving a balance of £11,178 2*s.* 7*d.* This balance is £834 10*s.* 4*d.* in excess of that with which the year 1875 was begun, and thus the expenses of the year 1875 have been £834 10*s.* 4*d.* within the true income of that year; the Council therefore feel that the Members may be well satisfied with the financial position of the Institution. The greater portion of the present balance is invested in £6000 London and North Western Railway 4 per cent. Debenture Stock, £1000 Midland Railway 4 per cent. Debenture Stock, £1000 Great Western Railway 4 per cent. Debenture Stock, and £2200 North Eastern Railway 4 per cent. Debenture Stock, registered in the names of Mr. Frederick J. Bramwell, Mr. Edward A. Cowper, and Mr. John Ramsbottom, as interim trustees on behalf of the Institution. The Finance Committee have examined and checked the receipts and payments of the Institution for the past year, and report that the following Abstract of Receipts and Expenditure rendered by the Treasurer is correct.

(*See Abstract appended.*)

The following Deceases of Members of the Institution have occurred during the past year:—

ROBERT NICOLL ANGUS, ... Stoke-upon-Trent.
JOHN JAMES BAGSHAWE, ... Sheffield.
CHARLES CLEWORTH, ... Manchester.

JOHN EDWARD CLIFT, ... Cheltenham.
JAMES DEES, ... Whitehaven.
PETER BOYD EASSIE, ... Gloucester.
HENRY WILLIAM HARMAN, ... London.
GEORGE HARRISON, ... Birkenhead.
CHARLES WILLIAM HAWKINS, ... Bombay.
EDWARD LORD, ... Todmorden.
JOSHUA LLEWELYN MORGAN, ... Abergavenny.
GEORGE PEEL, JUN., ... Manchester.
GEORGE TAYLOR, ... Leeds.
JOHN WEBSTER, ... Bahia.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. They trust the Members generally will promote the formation of a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Description and Plans of the Sea Ports of France; from the Minister of Public Works, Versailles.

On the Management of Commercial Ports, by L. Barret; from the author.

On the Theory of the Flow of Water in Open Channels, by Robert Gordon; from the author.

On Theoretical Kinematics, by Professor Reuleaux; from the author.

Report on the Strength of Single-riveted Lap Joints, by B. B. Stoney; from the author.

On Guns and Steel, by Sir Joseph Whitworth; from the author.

On the relative merits of Single and Compound Engines, by Niel McDougall; from the author.

On Planing Metals, by M. Tresca; from the author.

Elements of Practical Construction, with engravings, by Samuel Downing, LL.D.; from the author.

Manual of Metallurgy, vols. 1 and 2, by W. H. Greenwood; from the author.

On the principles of Metal Mining, by J. H. Collins; from the author.

Studies of Blast Furnace Phenomena, by M. L. Gruner, translated by L. D. B. Gordon; from Mr. Charles Cochrane.

Notes on a visit to Coal and Iron Mines and Iron Works in the United States, by I. Lowthian Bell; from the author.

On the Rise and Progress of the Cleveland Iron Trade, by John Gjers; from the author.

On River Pollution, by Jabez Hogg; from the author.

Professional Papers of the Corps of Royal Engineers; from the School of Military Engineering.

Lectures on Irrigation Works in India, and practical Engineering Construction; from the School of Military Engineering.

Lectures on Water Supply, Sewerage, and Sewage Utilisation, by Dr. W. H. Corfield; from the School of Military Engineering.

Discourse upon the Art of Architecture, as applied to Military Buildings, by John P. Seddon; from the School of Military Engineering.

Report of the Miners' Association for Cornwall and Devon; from the Association.

First Report of the Commissioner of the Imperial Mint, Japan; from Mr. Robert Maclagan.

Map showing the route of Railways at the Cape of Good Hope; from Mr. Michael Stephens.

Engravings from the École des Ponts et Chaussées, Paris, vol. 1.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Journal of the French Society for the Encouragement of National Industry; from the Society.

Journal of the Marseilles Scientific and Industrial Society; from the Society.

Journal of the Hanover Architect and Engineer's Society; from the Society.

Journal of the Saxon Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Transactions of the American Society of Civil Engineers; from the Society.

Transactions of the American Society of Mining Engineers; from the Society.

Smithsonian Institution Annual Report; from the Institution.

Proceedings and Journal of the Asiatic Society of Bengal; from the Society.

Proceedings of the Institution of Civil Engineers; from the Institution.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Institution of Engineers in Ireland; from the Institution.

Journal of the Iron and Steel Institute; from the Institute.

Proceedings of the Scientific and Mechanical Society of Manchester; from the Society.

Transactions of the Society of Engineers; from the Society.

Transactions of the Chesterfield and Derbyshire Institute of Engineers; from the Institute.

Proceedings of the Royal Society of London ; from the Society.
Report of the British Association for the Advancement of Science ; from the Association.
Transactions of the Institution of Naval Architects ; from the Institution.
Transactions of the Institution of Surveyors ; from the Institution.
Journal of the Royal United Service Institution ; from the Institution.
Proceedings of the Royal Artillery Institution ; from the Institution.
Journal of the Royal Agricultural Society of England ; from the Society.
Proceedings of the Royal Institution of Great Britain ; from the Institution.
Transactions of the Royal Scottish Society of Arts ; from the Society.
Proceedings of the Philosophical Society of Glasgow ; from the Society.
Report of the Manchester Steam Users' Association for the prevention of Steam Boiler Explosions ; from Mr. Lavington E. Fletcher.
Report of the National Boiler Insurance Company ; from Mr. Henry Hiller.
The Engineer ; from the Editor.
Engineering ; from the Editor.
Iron ; from the Editor.
The Mining Journal ; from the Editor.
The Railway Record ; from the Editor.

In the course of 1875 the Meetings held were the Anniversary Meeting, the London Meeting, the Summer Meeting, and the Manchester Autumn Meeting, in addition to a Special Meeting held in London in June for the consideration of the Patent Laws Bill. Two days were devoted at the Spring and Summer Meetings to the reading and discussion of Papers, making with the Anniversary and Autumn Meetings six days in all thus occupied in the course of the year. The list of Papers is as follows :—

On Jaques Oakley and Sterne's Electro-Magnetic Chuck for holding special work in lathes &c. ; by Mr. William E. Newton.
On the Manufacture and Testing of Portland Cement, and the Machinery used in its production ; by Mr. Henry Faija.
Some notes on the early history of Railway Gauge ; by Mr. William Pole, F.R.S.
On Rock Boring by the Diamond Drill, and recent applications of the process ; by Major Beaumont, R.E., M.P.
Description of a Direct-acting Circular Saw for cutting Steel hot ; by Mr. Francis W. Webb.
On the Floating Swimming Bath at Charing Cross, with the means adopted for the filtration of the water ; by Mr. Edward Perrett.
On Otto and Langen's Atmospheric Gas Engine, and some other Gas Engines ; by Mr. Francis W. Crossley.

On Direct-Acting Winding Engines for Mines; by Mr. George H. Daglish.
On Wood-Working Machinery; by Mr. Thomas N. Robinson.
On Fluid Compressed Steel and Guns; by Sir Joseph Whitworth, Bart., D.C.L., F.R.S.
On Mechanical Ventilators for Mines; by Mr. William Daniel.
On the Ultimate Capacity of Blast Furnaces; by Mr. Charles Cochrane.

The attendances at the Meetings were, at the Anniversary Meeting 47 members and 7 friends, at the Spring Meeting 85 members and 43 friends, at the Autumn Meeting 69 members and 38 friends, and at the Special Meeting 26 members and 24 friends.

The Summer Meeting was held in Manchester, being a re-visit to that place after an interval of nine years, and the result was very satisfactory; the attendance was 207 members and 91 friends, and the discussions at the meeting included some of special excellence and interest, particularly that upon the subject of fluid compressed steel. Excursions were made to many places of much interest and importance, including a visit to the Manchester Corporation Waterworks at Longdendale with its large reservoirs.

The Spring Meeting in London was a two days' meeting, as proposed in the last Annual Report; and was held, through the courtesy of the Council of the Institution of Civil Engineers, at the house of that Institution.

The Autumn Meeting was held in Manchester, in pursuance of the resolution come to last year; and the Council have reason to consider that the result was satisfactory, and that the holding of the Autumn meeting in Manchester will be useful in promoting the interests of the Institution.

With respect to the premiums which at the last anniversary meeting it was determined might be awarded to the authors of two sufficiently meritorious papers contributed in the course of each year, the Council have to report that, inasmuch as the papers read since the announcement of these premiums have as yet been produced at only three of the quarterly meetings, the time has not yet arrived for making any award.

The Index to the Proceedings of each successive year has been carried out for the last two years, as proposed by the Council, and

the General Index to the Proceedings of the previous years is in course of preparation, and will be issued as soon as possible, with the Library Catalogue.

The printing of each Paper previous to being read at the Meetings has been effected, as proposed, and has been found advantageous in working.

At the last Anniversary Meeting it was resolved that a sum of money be devoted to the investigation of questions connected with the science of Engineering. The mode of carrying out this object has been under the consideration of the Council, but is not yet sufficiently matured for immediate adoption.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the Rules of the Institution; and the ballot taken at the present meeting will show the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—extent of water surface—relation of grate surface to heating surface, and heating surface to fuel consumed—relative value of radiant surface and flue surface in effect and economy—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—combined air and steam—safety valves—water gauges—explosion of boilers, and means of prevention—strength and proportions of riveted joints, single and double riveting—welded joints—comparative strength of drilled and punched plates in iron and in steel—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—small water-space boilers for specially high pressures—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel; coal, wood, charcoal, peat, coke, and artificial fuel—mechanical firing, moveable grates and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed-water—mode of feeding—use of injector—circulation of water—self-acting feeding apparatus.

STEAM ENGINES—expansive force of steam, and best means of using it—effect of steam jackets—power obtained by various plans—comparison of double and single-cylinder engines—combined engines—compound-cylinder engines—comparative advantages of direct-acting and beam engines—horizontal and vertical engines—condensing and non-condensing engines—construction and particulars of working of injection and surface condensers—ejector condenser—air-pumps—piston speed—pistons, slide-valves, and other valves—governors—throttle valves—bearings, &c.—improved expansion gear—expansion gear controlled by governor—indicator diagrams from engines, comparison of these diagrams with dynamometer experiments, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—indicator diagrams from pumps—construction of pumps—plunger pumps—bucket pumps—rotary and centrifugal pumps—details of different pump valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

BLAST ENGINES, best kind of engine—details of construction—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from steam cylinder, blast cylinder, and blast main.

MARINE ENGINES, power of engines in proportion to tonnage—dimensions and form of vessel—different constructions of engines, compound-cylinder engines, trunk engines, oscillating engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—surface condensers—salinometers—weight of machinery, and boilers—speed obtained in different steamers, with particulars of construction of engines—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—economy of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood—construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast-pipe—construction of pistons, valves, expansion gear, &c.—balanced slide-valves—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—steam breaks, counterpressure steam break—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—ploughing engines—traction engines, particulars of performance and cost of work done.

STEAM ROAD ROLLERS, particulars and results of working.

HOT-AIR ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—accumulator—hydraulic machinery—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—stone-dressing machinery.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in opening, carding, spinning, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

WEAVING MACHINERY, for manufacture of different materials—improvements in looms, &c.

LACE MACHINERY, particulars of improvements.

KNITTING MACHINERY, worked by hand or by power—particulars of improvements.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws—saw sharpeners.

WOOD-WORKING MACHINES, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

STONE-WORKING MACHINERY — cutting, planing, turning, and polishing machines.

GLASS MACHINERY — manufacture of plate and sheet glass — grinding and polishing machinery—construction of melting furnaces, annealing kilns, &c.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolling mills.

HAMMERS, improvements in construction and application—steam hammers—friction hammers—air hammers—tilt hammers.

RIVETING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines — rivet-making machines — comparative strength of hand and machine riveting—plate-bending and flanging machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or by hydraulic power, ditto.

CRANES—steam, hydraulic, and pneumatic cranes—travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses, blast-furnaces, &c.—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery—cutting teeth by machinery.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, adhesion, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained — friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

PRESSURE GAUGES, for steam and water — varieties of construction — durability and results of working—speed indicators for vessels and trains.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS—facts relating to experiments, and general details of testing—influence of temperature on strength.

GIRDERS OF CAST AND WROUGHT IRON, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks—friction of ropes.

ROOFS, particulars of construction for different purposes—cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost—durability in various climates and situations—comparative cost, weight, and durability.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials—means of rendering timber &c. incombustible.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

GAS WORKS—best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas-meters—self-regulating meters—pressure of gas—gas-exhausters, construction and results of working—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments

on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

WATER WORKS, facts relating to—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—incrustation in pipes, effect on delivery, and means of prevention or removal—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—relief valves—machinery for working sluices—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFERDAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons—particulars of construction.

PILE-DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

EXCAVATING MACHINES, construction and results of working.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

SUBAQUEOUS ENGINEERING, particulars of works.

LIGHTHOUSES, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—iron and steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam and hydraulic power to steering—instruments to record rolling of ships and to ascertain stability.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—shot and shells, cast-iron and steel, manufacture and proof.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.—breech-loading mechanism.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, dynamite, &c.—effects produced by large and small charges of powder—arrangement of charges.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—rock-drilling machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials

—safety guides—winding machinery—hauling arrangements underground and at surface—stone-breaking machines—mode of breaking, pulverising, and dressing various descriptions of ores—coal-washing machinery.

BLAST FURNACES, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace, and mode of charging.

PUDDLING FURNACES, best forms and construction—gas furnaces—application of machinery to puddling.

SMELTING FURNACES, for reduction of copper, tin, and lead ores, &c.—best construction and modes of working.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CUPOLAS, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

BLOWING FANS, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

VENTILATING FANS for mines—ventilating machines—mechanical ventilation and warming of public buildings.

FUEL, solid, powdered, liquid, gaseous.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal-slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS—construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals—interlocking apparatus for signals and points—switch locks.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—construction—laying and picking-up machinery.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks—steam, air, and hydraulic breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—self-acting couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture—durability, and causes of fracture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left edge. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

Abstract of Receipts and Expenditure,

For the year ending 31*st December* 1875.

Cr.				£	s.	d.
By Balance 31st Dec. 1874; Invested	9178	16	2			
In Bank	1014	16	1			
Cash in hand	150	0	0	10,343	12	3
„ Subscriptions from 33 Members in arrear				99	0	0
„ do. 1 Associate do.				3	0	0
„ do. 829 Members for 1875				2487	0	0
„ do. 25 Associates do.				75	0	0
„ do. 32 Graduates do.				64	0	0
„ do. 13 Members in advance				39	0	0
„ do. 3 Life Members				90	0	0
„ Entrance Fees from 73 New Members				146	0	0
„ do. 4 New Associates				8	0	0
„ do. 4 New Graduates				4	0	0
„ do. 3 Graduates transferred to Members				3	0	0
„ Sale of Extra Reports				53	0	0
„ Interest; From Bank	19	9	5			
On £9200 Stock at 4 p. c. one year, less inc. tax	364	18	8			
On £1000 Stock at 4 p. c. 141 days, less inc. tax	15	6	5	399	14	6
				£13,814	6	9

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	880	9	4			
Less Authors' copies of Papers, repaid	32	1	0	848	8	4
„ Stationery, Binding, Printing of Circulars, &c.				108	10	0
„ Office Expenses, Clerks, and Petty Disbursements				107	9	9
„ Coals, Gas, and Water				37	13	6
„ Expenses of Meetings				145	5	10
„ Fittings and Repairs				10	7	3
„ Travelling Expenses				70	10	4
„ Parcels				4	11	5
„ Postages				130	6	8
„ Salaries				1050	0	0
„ Insurance				2	10	0
„ Rent and Taxes				120	11	1
Balance 31st Dec. 1875; Invested	10,188	16	2			
In Bank	839	6	5			
Cash in hand	150	0	0	11,178	2	7
				£13,814	6	9

(Signed) CHARLES COCHRANE,
EDWARD A. COWPER,
WALTER MAY,
} Finance Committee.

27*th January* 1876.

MEMOIRS

OF MEMBERS DECEASED IN 1875.

ROBERT NICOLL ANGUS was born on 6th January 1811 at Blebo Craigs, near Cupar, Fifeshire; and at the age of fourteen was apprenticed to Mr. David Fernie, engineer and millwright, Cupar, with whom he remained nine years. He then went to Glasgow for three years, in order to gain further experience; and next entered the service of Messrs. Bury Curtis and Kennedy, Clarence Foundry, Liverpool, remaining with them eight years; during this time he was engaged principally in the construction of locomotive engines, a large number of which he took out to the principal railways in England and Scotland, and at the opening of the Edinburgh and Glasgow Railway he drove the first engine from Glasgow to Edinburgh. He then became Locomotive Superintendent of the Preston and Wyre Railway, which position he held for four years, until his appointment as Locomotive Superintendent of the North Staffordshire Railway; there he remained until his death, a period of twenty-eight years, during the latter portion of which he designed and made a large number of useful machines for economising labour in the construction and repairing of locomotive engines. He died on 10th July 1875, in the 65th year of his age. He became a Member of the Institution in 1862.

JOHN JAMES BAGSHAWE, of the Thames Steel Works, Sheffield, was born on 13th September 1835 in Sheffield, where he resided until his death, which took place on 1st September 1875, in the 40th year of his age. He became a Member of the Institution in 1865.

Charles Cleworth was born at Atherton near Manchester on 1st March 1831, and served his apprenticeship to mechanical engineering with Messrs. Sharp Stewart and Co., Atlas Works, Manchester, by whom he was afterwards employed for some time in taking out their engines to Russia, Poland, and the West Indies. In 1862 he went under Mr. Armstrong, locomotive superintendent of the Great Western Railway, to gain an insight into railway working; and in 1863 he was appointed a District Locomotive Superintendent on the East Indian Railway. This situation he retained till the time of his death, being stationed successively at Allahabad, Jumalpore, and Howrah. On returning to India in 1872 after a visit to England, he was attacked by fever, which laid the foundation of a fatal disease, that necessitated his return to England at the end of 1874; after a temporary improvement of health during the next few months, the disease of heart and brain increased rapidly, and his death took place on 15th September 1875, at the age of 44. He became a Member of the Institution in 1866.

John Edward Clift was born at Handsworth, near Birmingham, on 11th April 1817. He was a pupil of Mr. John Brunton, engineer to the Birmingham and Staffordshire Gas Company, whose only works at that time were situated at Swan Village, Westbromwich. On Mr. Brunton's retiring, Mr. Clift succeeded him as Engineer to the company, which position he held for more than twenty years. During that time he designed and constructed a second gas works for the company, the Pagoda Works in Adderley Street, Birmingham; and the demand for gas increasing so rapidly, in 1858 he began a third gas works for the company, at Saltley. Under his management the company prospered greatly, paying high dividends and accumulating a large reserve fund. In 1858 he resigned his appointment with this company, and was invited to Redditch to construct gas works there, which he did on his own account, and the town was successfully lighted in 1859; these works were transferred to a company in 1873, in consequence of his health failing. Mr. Clift also built the gas works at Longton and at Rowley Regis; and acted as consulting engineer to the gas works

at Lincoln, Gainsborough, Tring, Grantham, Weston-super-mare, Oswestry, Chesham, and other towns. At many of these works the firebrick gas retorts or ovens introduced by him, and known by his name, have been successfully at work for a number of years, in place of the former cast-iron retorts; of these retorts he gave a description to the Institution in 1852 (see Proceedings Inst. M. E. 1852 page 178). In 1859 he went to Paris to report upon the gas works there; and in 1864 to Russia with a view of erecting new works at Moscow and St. Petersburg. He had a great deal of parliamentary business in connection with gas works, and was instrumental in getting many bills passed. In September 1873 he retired to Cheltenham for the benefit of his health; and his death took place suddenly at his residence, Mayfield, Cheltenham, on 26th April 1875, at the age of 58. He was one of the original Members of the Institution from the commencement in 1847, and an active member of the Council for many years.

JAMES DEES was born at Meldon near Morpeth, Northumberland, on 14th March 1815. Having chosen the profession of civil engineer, he went in 1845 to Whitehaven, Cumberland, as Resident Engineer of the Whitehaven and Furness Railway then being constructed under Mr. George Stephenson, Mr. Robert Stephenson, and Mr. Longridge. After completing that line, extending from Foxfield to Whitehaven, and also the Whitehaven Tunnel connecting the Furness line with the Whitehaven Junction Railway, he was appointed engineer of the first wet dock at Maryport, which he successfully finished. He was one of the promoters of the scheme for making a railway from the hæmatite district in that neighbourhood, which resulted in the opening in 1856 of the Whitehaven Cleator and Egremont Railway, Mr. Dees being chief engineer and subsequently a director. About 1853 he commenced the Whitehaven brick and tile works, of which he was sole proprietor; and he was one of the most energetic promoters of the Solway Junction Railway, of which he was a director and deputy chairman. He was also a partner in the Parkside Mining Co., whose extensive operations are well known. He was a magistrate for the counties

of Cumberland and Northumberland. He died at his residence, Riverdale, Bellingham, Northumberland, at the age of 60, on 19th September 1875, after but a few hours' illness of internal hemorrhage. He became a Member of the Institution in 1858.

Peter Boyd Eassie was born at Lochee, Forfarshire, on 17th April 1835. He was for some years partner with his father, Mr. William Eassie, and his brother, railway contractors and proprietors of the Railway Saw Mills, Gloucester, and was latterly manager of the same concern under the firm of William Eassie and Co. He carried out many successful railway and other contracts, involving difficult cases of practical engineering, in which peculiar machinery had to be invented by him; and among his many successful inventions were an elliptograph, a frictional steam hammer in use in Scotland so constructed that several steam hammers can be driven by one engine, an improved swing saw, and a self-acting steam pile-driver, adopted by the Admiralty at Chatham and Portsmouth, of which he gave a description to the Institution in 1867 (see Proceedings Inst. M. E. 1867 page 255). He was the author of a work upon "Wood and its uses," which met with an extensive circulation in this country and America; and he had lately completed a pamphlet on the wages question, embodying much original thought. His death, which was entirely traceable to overwork, took place on 26th June 1875, at the age of 40. He became a Member of the Institution in 1859, at which time he was engaged upon the construction of the Cornwall Railway.

Henry William Harman was born in 1815, and served his apprenticeship with Messrs. Maudslay and Field, London. In 1840 he entered the service of the Great Western Steam Ship Co. at Bristol, and assisted in superintending the construction of the "Great Britain." On her completion in 1845 he became chief engineer at Mr. W. Pitcher's dockyard, Northfleet, until 1858, during which time many well-known vessels were constructed there. In 1859 he was appointed Chief Engineer to the Manchester Association for the prevention of Steam Boiler Explosions, from

which he retired in 1861 to take the management of the business of Messrs. Wm. Fairbairn and Co., Manchester, and on its transformation into the Fairbairn Engineering Co. he was retained as engineer and manager, which position he resigned in 1873 owing to failing health. After travelling on the Continent for a time he returned to England apparently restored; but shortly afterwards was attacked by a painful and protracted illness, from which he died on 28th September 1875, at the age of 60. He became a Member of the Institution in 1859.

GEORGE HARRISON was born in Liverpool on 4th June 1815. After serving his apprenticeship as an engineer with Messrs. Mather Dixon and Co. of Liverpool, and Messrs. Jones of Newton-le-Willows, he went to France, and became Locomotive Superintendent at Paris of the Paris and Rouen Railway on its opening in 1843, and remained there until appointed Locomotive and Carriage Superintendent of the Orleans and Bordeaux Railway; this appointment he held until the revolution of 1848, which compelled him to return to England. He afterwards became Locomotive Superintendent of the Scottish Central Railway, and other lines associated with it, which appointment he held until the construction of the Grand Trunk Railway of Canada in 1853. He was then consulted by Messrs. Peto Brassey and Betts, in reference to the construction of the locomotives for this railway, and thereupon visited Canada; and on his report it was decided to establish works in England in preference to Canada, for the construction of the locomotives and the wrought-iron bridges. The Canada Works at Birkenhead were accordingly established, with which he remained connected up to the time of his death. Here the great bridge over the river St. Lawrence was made; and since the completion of the Grand Trunk Railway, the works have been successfully carried on under his supervision, having executed railway work of a gigantic character for lines in this and many other countries. Mr. Harrison was also for a time manager of the Millwall Iron Works, London, and of the Humber Iron Works, Hull. Twenty years ago he became a Commissioner for Birkenhead, and was the first to

propose the introduction of the large saloon steamers at Woodside Ferry on the river Mersey; he never ceased agitating the question at the meetings of the Board, until the present splendid class of ferry steamers were placed on the station. The new portion of the great landing stage at Liverpool was constructed at the Canada Works, but on the eve of its completion was destroyed by fire; the anxiety consequent upon this unfortunate accident preyed much upon Mr. Harrison's mind, and he had a great desire to see the re-construction completed. His health however failed before the work was accomplished, and he died in London on 1st June 1875, in the 60th year of his age. He became a Member of the Institution in 1856, and was for many years a member of the Council.

Charles William Hawkins, son of the Rev. H. A. Hawkins, Vicar of Topcliffe, Thirsk, was born on 8th July 1839. He served his apprenticeship in the locomotive works of Messrs. R. Stephenson and Co., Newcastle-on-Tyne, in whose employment he afterwards continued as draughtsman until 1861; and then went to Doncaster under Mr. Archibald Sturrock, locomotive superintendent of the Great Northern Railway, serving as a fitter in the running shed and also as fireman on goods and passenger trains. In 1865 he became District Locomotive Superintendent at Leeds, where he remained until 1869, when he was appointed Locomotive and Carriage Superintendent of the Great Indian Peninsula Railway, embracing 1275 miles of opened line. He was characterised by great energy and ability, and held this position till his death, which occurred suddenly from heart disease on 3rd August 1875, at the age of 36. He became a Member of the Institution in 1873.

Edward Lord was born on 1st March 1812, being the youngest son of Mr. John Lord of Todmorden, who in 1835 commenced with six of his sons the business of machinists at Clough Walsden, subsequently removing to the Canal Street Works, Todmorden, where the two businesses of machinists and cotton spinners were carried on under the firm of Lord Brothers, of which Mr. Edward Lord was the last surviving member. It was no doubt to his business

aptitude and mechanical skill that the leading position of the firm was greatly due, their business extending to every country where cotton machinery is employed; and his name is associated with some of the most useful inventions in that class of machinery. He also gave his support to every means for the prosecution of scientific enquiry. He was one of the founders of the Carnforth Hæmatite Iron Co., and a director of the Norton Iron Co., the Beverley Iron Co., and many other companies in England and elsewhere. His death took place at his residence, Adam Royd, Todmorden, on 10th September 1875, in the 64th year of his age. He became a Member of the Institution in 1866.

Joshua Llewelyn Morgan was born on 10th April 1820, at Llanelly, Breconshire, and studied engineering and chemistry at King's College, London. His first engagement of any consequence was that of furnace manager at the Victoria Iron Works, Monmouthshire, and in 1847 he was appointed assistant manager of the Cwm Avon Copper Works. In 1849 he went out to Australia and visited the celebrated Burra Burra Copper mines and others; he then went to Sydney, New South Wales, and on his way inspected the Fitzroy Iron Works by the desire of the owners. In 1850 he formed with other gentlemen a company for smelting copper, of which he was appointed manager, and erected works for that purpose at Burwood, near Newcastle, on the Hunter river. In 1852 large coalfields in the vicinity were added to the property of the company, and they then carried on operations under the title of the Newcastle Coal and Copper Co. The discovery of gold in the neighbouring colony of Port Philip just at that time rendered all manufacturing industries nearly impossible, in consequence of the scarcity of labour; and in 1853 the company abandoned the copper works, and developed more fully their rich coalfields. Mr. Morgan continuing to act as manager made a railway for the conveyance of coal from Burwood to Newcastle, overcoming great difficulties in the form of almost impracticable country and great scarcity of competent assistance. In 1855 he was engaged to conduct an experiment which had previously failed

for smelting copper ore with wood as fuel, at a place called Ophir, about 100 miles from Sydney; he reconstructed the works on his own principle and succeeded in the experiment. He afterwards returned to his former post of manager of the Newcastle Coal and Copper Co., which he retained till 1864, when he returned to England. He did not at once engage in any employment, but visited the principal ironworks in England and Wales, and studied assiduously all the latest improvements in his profession. In 1869 he became manager of the Clydach Iron Works, Breconshire, which post he held till 1874, when he became managing partner of the Wildon Iron Works, near Abergavenny; these works he reconstructed thoroughly, and was managing them as successfully as the depressed state of trade would admit, when he met with an accident in the works, which was the cause of his instant death, on 5th January 1875, in the 55th year of his age. He became a Member of the Institution in 1864.

George Peel, Jun., was born in Manchester on 24th February 1828, and became early connected with the firm of Messrs. Peel Williams and Peel, Soho Iron Works, Manchester; he did not serve any time in the shops, but his many years' experience at the works gave him a thorough insight into the requisites and niceties of good work. His death took place in London on 10th March 1875, at the age of 47, after a long and painful illness. He became a Member of the Institution in 1866.

George Taylor was born at Low Moor, near Bradford, on 8th August 1820, and in early years served at the Low Moor Iron Works as a hammerman; he afterwards entered the works of Messrs. Cooper Field and Hood, Leeds, where he remained until 1857. In conjunction with his brothers, James and Samuel Taylor, he then established the Clarence Iron Works, Leeds, for the manufacture of best Yorkshire iron, adding afterwards the manufacture of crucible cast steel. He distinguished himself particularly in the manufacture of large forgings, such as locomotive crank-axles, for which his firm enjoyed a high reputation, he himself having been one of the

earliest workmen who forged a locomotive double crank-axle from one solid piece of iron; and he was well known for his skill in that description of work. After his brothers' death he continued to carry on the business until the time of his death, which occurred on 19th June 1875, in the 55th year of his age, from the bursting of a blood vessel. He became a Member of the Institution in 1861.

JOHN WEBSTER was born at Aberdeen in September 1840, and received his training as an engineer in the works of Messrs. Mackinnon and Co., Aberdeen. In 1860 he went to Bahia, Brazil, as draughtsman and millwright to Messrs. Cameron Smith and Co. for three years. He then commenced business at Bahia with Mr. Hopkins under the firm of Hopkins and Webster, which was very successful, employing 250 workmen. His death was occasioned by an accident in the works on 27th December 1875, at the age of 35. In the same week the first iron steamer built in Bahia was launched from the works. He became a Member of the Institution in 1875.

The Annual Report of the Council having been received and adopted by the Meeting, the Chairman announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year:—

PRESIDENT.

THOMAS HAWKSLEY, ...	London.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, M.P., F.R.S., .	Middlesbrough.
JOHN HICK, M.P., ...	Bolton.
WILLIAM MENELAUS, ...	Dowlais.
JOHN ROBINSON, ...	Manchester.
CHARLES P. STEWART, ...	London.
PERCY G. B. WESTMACOTT, . .	Newcastle-on-Tyne.

COUNCIL.

DANIEL ADAMSON, ...	Manchester.
JOHN ANDERSON, LL.D., F.R.S.E., .	London.
JOSEPH ARMSTRONG, ...	Swindon.
HENRY BESSEMER, ...	London.
JEREMIAH HEAD, ...	Middlesbrough.
HENRY H. LAIRD, ...	Birkenhead.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . .	Newcastle-on-Tyne.
FREDERICK J. BRAMWELL, F.R.S., .	London.
JAMES KENNEDY, ...	Liverpool.
ROBERT NAPIER, ...	Glasgow.
JOHN PENN, F.R.S., ...	London.
JOHN RAMSBOTTOM, ...	Manchester.
C. WILLIAM SIEMENS, D.C.L., F.R.S.,	London.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., ...	Manchester.

COUNCIL.

Members of Council remaining in office.

CHARLES E. AMOS,	London.
E. HAMER CARBUTT,	Bradford.
WILLIAM CLAY,	Birkenhead.
CHARLES COCHRANE,	Stourbridge.
EDWARD A. COWPER,	London.
EDWARD EASTON,	London.
FREDERICK W. KITSON,	Leeds.
WALTER MAY,	Birmingham.
FRANCIS W. WEBB,	Crewe.

Mr. BRAMWELL said it was with sincere pleasure that he called upon Mr. Hawksley to take the Chair, to which he had been elected by the votes of the Members; and he was sure in that election they had consulted the interests of the Institution, and he congratulated them upon Mr. Hawksley's election as President.

Mr. HAWKSLEY, on then taking the Chair, expressed his thanks to the Members for the honour they had done him in electing him President of the Institution. During his term of office he should certainly do all in his power to promote the best interests of the Institution. It was a growing Institution, which promised to become of the greatest importance to the country, and was certainly not unimportant at the present time. So far as he could contribute to its advancement during the period that he had the honour of occupying the presidential chair, the Members might rely upon his best efforts.

The following New Members were declared to be duly elected:—

MEMBERS.

WILLIAM ARMSTRONG, JUN.,	Durham.
WILLIAM CARSON,	Birkenhead.
WILLIAM JOHN COE,	Liverpool.
JOHN DONALDSON,	London.
JOHN CORRY FELL,	London.

WILLIAM FROST,	Sheffield.
WILLIAM PRIDEAUX NAISH,	Birmingham.
JAMES SALKELD ROBINSON,	Rochdale.
WILLIAM SMETHURST,	Wigan.
JOHN SMITH,	Rochdale.
CHRISTOPHER SPRIGGS,	Manchester.
JOHN ISAAC THORNYCROFT,	London.
RICHARD FRANCIS TREVITHICK,	Rosario.
SAMUEL WILLIAM WORSSAM,	London.

GRADUATE.

JOSEPH DAVIS,	Manchester.

Mr. A. PAGET moved that, with a view to making the Rules accord with the practice of the Institution, the first article of section V be altered to stand as follows:—"There are to be four General Meetings in each year, three to be held in Birmingham or London, *or elsewhere*, on the fourth Thursday in the months of January, April, and October, *or on such other dates as the Council shall deem more convenient*, and the fourth to be an Annual Meeting held in the summer in different localities to be arranged by the Council; the January Meeting to be the Anniversary Meeting for the annual election of officers." He stated that the only object of the proposed alteration was to give the Council power by the rules for appointing the meetings on the days that might be found most convenient in each case, as it had proved advantageous sometimes to vary the dates of the meetings from the days originally appointed by the rules.

The resolution was seconded by Mr. H. Chapman, and passed unanimously.

Mr. A. PAGET moved that the third article of section III be altered to stand as follows:—"All applications for admission to be communicated by the Secretary to the Council for their approval, previous to being inserted in the ballot list for the election; and the approved ballot list to be then forwarded to the Members. The ballot list to specify the name, occupation, and address of

the candidates, and also by whom proposed and seconded. The lists to be opened only *in the presence of the Council* on the day of election, by a committee to be appointed for that purpose." He said that the resolution was intended only to make the rules correspond with the practice in the mode of opening the ballot papers; and he thought that the system according to the rules, or the one now proposed would be equally satisfactory, and the only important point was that the rules and the practice should accord.

Mr. BRAMWELL seconded the resolution, and said that the practice had been adopted only for the purpose of saving the time of the meetings, and was found to work well, and he thought it therefore advisable for the rules to be made to accord with the practice.

The resolution was passed unanimously.

Mr. A. PAGET moved "That this Meeting requests the Council to ask by circular the opinion of each Member of the Institution as to whether it is desirable to move the head-quarters of the Institution to London." He said that power had already been given to the Council to ask the opinion of the Members by circular upon any question respecting the Institution, in order to enable the Council to conduct the Institution in accordance with the wishes of the members. The object of the resolution was to obtain the opinion of the members upon the question whether London or Birmingham was the best town for the head-quarters of the Institution.

Mr. J. PLATT seconded the resolution, and said he thought it was desirable that the question should be settled, and to facilitate this the views of each Member ought to be ascertained.

Mr. J. WRIGHT considered that as the head-quarters of the Institution had been established for a great number of years in its present position in the centre of the country in the Midland Counties, and many of the members had joined it on that account, its position was the most convenient, and he objected to any removal.

Mr. W. L. WISE remarked that the present question was not whether the Institution should be removed to London, but the object of the motion was to ascertain whether the majority of the Members considered the head-quarters should be there; and any resolution come to would not in any way commit the Institution on the main question.

Mr. C. W. SIEMENS objected to the resolution on the grounds that full powers had already been given to the Council for acting in the manner proposed whenever they might consider it desirable in the interests of the Institution; but the decision about this rested with the Council who were necessarily in the best position for judging about its desirability, and the resolution proposed would be as it were a reproach on the Council. He suggested that the proper course for carrying out the object of the resolution would be to memorialise the Council on the subject.

Mr. E. A. COWPER considered the resolution unnecessary as the Council had already the power to issue a circular for ascertaining the opinions of the Members, but it would not be suitable for this to be done on every question that might be raised. He thought more time should be given for the consideration of the subject by the Council, and that this would be best left in the hands of the Council, who felt the greatest interest and anxiety to do the best possible for the Institution; and he thought the Members might have full confidence that the subject would be properly dealt with by them.

Mr. BRAMWELL thought that the resolution was not a proper one to be put, as it tended to coerce the Council in their action; and it was certain that no Institution could be satisfactorily carried on if the Council were not allowed to exercise their proper discretion and were controlled by resolutions giving directions as to what they ought to do. The proper course was to memorialise the Council upon any question that might arise.

Mr. JEREMIAH HEAD considered that presenting a memorial was the only proper course, and urged the withdrawal of the resolution.

Mr. R. H. TWEDDELL was sure that in the proposal of the resolution there had not been any idea of interfering with the action of the Council, and no intention of implying any doubt that they would carry out whatever was best for the interests of the Institution.

Mr. P. D. BENNETT thought a memorial to the Council was the respectful mode of proceeding in the matter, but he could not understand why there should be the frequent attempts to alter the constitution of the Institution and remove it from the town where it had been established, where its present position in the mechanical world had been achieved, and where therefore its permanent home should remain.

Mr. C. COCHRANE said if the removal to London should really be for the interest of the Institution he would cheerfully see it removed; but he thought a memorial to the Council was the proper way to deal with the matter, and was sure the Council had no other interest in view than that of the Institution.

Mr. A. PAGET said that he had certainly been taken by surprise in this matter, he thought both his general conduct in his endeavours for the good of the Institution and the wording of his resolution gave proof that he had no wish to coerce the Council in the slightest degree. It had been known since he gave notice of this resolution at the Nov. meeting that he intended to bring it forward at this meeting, but until now he had received no intimation that the resolution would be considered by the Council as in any way objectionable, or that they would prefer a memorial; if any such intimation had been given to him it would have received immediate consideration, but he thought it was rather late to be told only now that the Council objected to the resolution and would prefer a memorial. However to show that he had not the slightest wish to oppose the Council or

to put any slight upon them, either imaginary or real, he would withdraw the resolution and would pledge himself to prepare a memorial and get it signed by those members who wished to do so; the withdrawal of the resolution must be subject to the consent of the meeting, because he felt pledged to many members to bring this matter forward.

The PRESIDENT expressed his approval of the suggestion to withdraw the resolution and substitute a memorial to the Council. The resolution was then withdrawn by consent of the meeting.

Mr. A. PAGET said he had given notice of another resolution, "That this Meeting requests the Council to ask by circular the opinion of each Member of the Institution as to whether the scientific papers shall be allowed to give reports of the meetings or not; and to communicate the result to the Members," but he had since perceived that an addition was required for meeting any occasion when it might not be desirable in the interests of the Institution for the proceedings to be made public; and if the Council had not stated that they preferred a memorial to a resolution he should have proposed to add to this resolution that "if at any meeting a majority of the members resolve that any part of the meeting shall be private, all visitors shall then be requested to withdraw, and the members shall regard the proceedings as private, and not to be communicated to any one except members of the Institution." However as the Council preferred a memorial, he would withdraw the resolution, with the intention of bringing the subject forward in a memorial.

The adjourned discussion was then resumed upon the paper read at the last meeting, "On the Ultimate Capacity of Blast Furnaces," by Mr. Charles Cochrane, of Stourbridge, (see Proceedings Inst. M. E. Nov. 1875 page 334.)

ON THE ULTIMATE CAPACITY OF BLAST FURNACES.

BY MR. CHARLES COCHRANE, OF STOURBRIDGE.

(*Adjourned Discussion.*)

Mr. C. W. SIEMENS was happy to bear testimony to the value of the practical information contained in the paper under discussion. The subject of blast-furnace economy had been brought before the Institution some years ago by Mr. Cochrane, from whom he had at that time been obliged to differ as to some of the conclusions then drawn. In the present paper it was admitted that the theories previously advanced had not been fully realised; but the correctness of the former views was still maintained, and the defects were attributed to the imperfect working of the furnaces.

The title of the present paper—on the ultimate capacity of blast furnaces—was one from which he differed entirely, for he considered as an abstract principle there could be no such thing as an ultimate capacity. It was possible to conceive that, under the condition of charging the furnace with perfectly uniform materials, one form of furnace might be more suitable for developing maximum results than another; but even in that case he would not go so far as to say that these maximum results would be attained with a particular capacity or a particular height of furnace. The operation performed in the furnace was simply a chemical one: the ironstone was first heated, and then acted upon chemically and then smelted, and tapped from the bottom of the furnace. He did not see what there was in this operation, more than in any other chemical process, which should predispose it to give the best results when carried out on a particular scale; and he believed that the same chemical action would be carried on in precisely the same manner in two blast furnaces, one of which was only half the capacity of the other, and blown with only half the quantity of

blast, and that the same results in economy of fuel would be realised in both furnaces. If it were attempted to give a general application to the principle advocated in the paper, his own observations would lead him to differ entirely; for in South Wales, for instance, where the hard Durham coke of the Cleveland district could not be obtained, and the coke used was extremely weak, it would be quite out of the question to erect a furnace of such height and capacity. But he considered that, in the case of the Cleveland district, the objection applied equally against the theory of an ultimate capacity attended with a maximum economy of fuel. It appeared to him that the paper omitted to take cognisance of the chemical action going on in the furnace; the heat-absorbing capacity of the material, and the consequent reduction in temperature of the escaping gases, seemed to be taken as the only criterion by which the results ought to be judged. But it must surely be admitted that the economical results must depend largely upon the chemical conditions of the operation. If in one case, the escaping gases contained no carbonic acid but only carbonic oxide, and in another case the carbonic oxide was accompanied by 20 or 30 per cent. of carbonic acid, the result must be widely different in economy, even though the temperature of the escaping gases at the furnace top might be the same in both cases. If this element—the chemical result of the operation—were taken proper cognisance of, the mere question of capacity would sink into the second place, and the chemical action would be the most important consideration for blast furnaces. As a record of results on a large scale he thought the paper was extremely valuable.

Mr. E. A. Cowper did not quite agree in the identity of the action taking place in blast furnaces of different sizes. Supposing there were two furnaces, one exactly half the size of the other, and supposing exactly the same action took place in both, then of course one would simply be doing twice as much work as the other, with the same result in economy of fuel; but he did not think that in the actual working of blast furnaces the same result would be obtained in one furnace as in another of twice the size; and this was the

whole question. By increasing the capacity of furnace beyond what was sufficient for the completion of the chemical action, the further advantage claimed in the paper was obtained, of gaining in addition *a heating zone*, in which little or no chemical action took place, but in which heat that would otherwise have escaped from the furnace was saved, and was utilised for heating the incoming materials. By this means the same additional economy was realised that would be obtained by heating the materials beforehand, instead of charging them cold.

Mr. COCHRANE said, in reply to Mr. Bell's observations, it was evident that he was still impressed with the correctness of his formerly expressed opinion that there is a positive evolution of heat in the upper region of a blast furnace which must defeat any attempt to abstract sensible heat from the gases after a capacity of say 15,000 cub. ft. has been attained, and after the temperature of the escaping gases has been lowered to about 560°, whilst he alluded to 782° as something like a maximum and 464° as a minimum for their temperature in regular work. On the accuracy of this opinion or deduction now turns the entire difference under discussion, for it will be observed that at a furnace of 15,000 cub. ft. Mr. Bell now claims to be working with as little as 20·70 cwt., which by the way is 2 cwt. better than he claimed for a furnace of such capacity when he laid down his curve. No one will more frankly admit than he that if the temperature of the escaping gases can be lowered 200° by opposing additional incoming material to its influence, there is room to save nearly 2 cwt. of fuel per ton of iron made, which would reduce his consumption to 18·70 cwt. That such lowering of temperature is possible is incontestibly shown by hourly observations over many months, and it has been not the least gratifying part of the writer's observations to find that during the eight months, January to September 1875, the temperature of escaping gases at the furnace of 33,140 cub. ft. capacity was reduced to 374°, which was to within 9° of what was expected to be reached, by the addition of 13,452 cub. ft. to the furnace of 20,624 cub. ft. On no point was he clearer than that this

reduction in temperature has been accomplished. That Mr. Bell has failed to discover any difference in the temperature of escaping gases at furnaces of 11,500, 11,600, 15,400, 17,500, 22,000, and 25,500 cub. ft., only proves that these furnaces were in the case of not working up to their effective capacity, and assuredly cannot disprove the positive results attained at Ormesby Iron Works. He urged, by way of attempting to disprove the accuracy of the writer's observations, that to have attained such a low average as 374° you must believe that the larger furnaces suffer similar fluctuations in their temperature as do lesser furnaces: so with 342° fluctuation on either side of 374°, there should at one time be a temperature more than high enough to melt lead, 716°, and at another low enough to freeze water. But it is one of the direct results of the increased capacity that such wide and objectionable fluctuations cease, and are limited to about 80° on either side of the average of 374°; so that the lowest temperature attainable is about 294°, and the highest that need exist 454°. Nor are these low temperatures, as Mr. Bell surmises, due in any appreciable degree to the possible influence of moisture in the coke, which by evaporation and the absorption of sensible heat into latent might tend to lower the temperature of the escaping gases. Every day's coke has been carefully analysed over the entire period of the observations, and the annual results are shown under the column "Impurities in the Coke." It will be seen that in 1875 the average percentage of water was only 0·46 over the eight months, so that the coke could only have contributed 0·46 cwt. $\times \frac{20{\cdot}69}{100} = 0{\cdot}09$ cwt. to the average weight of the escaping gases, which at 20·69 cwt. of coke per ton of iron would amount to $132{\cdot}4 \times \frac{20{\cdot}69}{21{\cdot}15} = 127{\cdot}41$ cwt. The addition to this of such a small quantity of moisture as 0·09 cwt. need not for a moment be considered as influencing the results of the observations made.

Mr. Bell was unwilling to believe in the explanation or rather theory of a working effective capacity, which so far as the term is used in the paper relates only to duty done by coke per ton of iron made, the normal materials of Cleveland being always understood; but when he is told that there has been positive evidence of the

truth of this in the working of the furnace of 40,500 cub. ft. capacity in 1871-1872 he may admit its accuracy. For many consecutive months that furnace worked almost entirely over the back tuyeres, so that for one charge put on at the front of the furnace several were put on at the back. This could only arise from a mechanical obstruction, the size of which could be measured so far as concerned its influence on temperature of escaping gases. In 1871 this obstruction amounted to more than half its total capacity: not necessarily that there was a solid scaffold of this magnitude fused together in one mass, but that a solid obstruction existed below over the forepart, which had all the effect of a solid one all the way up. In 1872 this obstruction was reduced to about 18,000 cub. ft. The scaffolds sometimes broke away from the sides of the furnace, shaking the furnace sides with the shock of their fall, and making the ground shake beneath the feet. It will not be a matter of surprise that such a furnace only lived a couple of years. Happily no such difficulties have to be encountered in the furnace of 33,140 cub. ft. capacity, because the causes have been removed which led to the bad working in 1871-1872 of its larger predecessor. That furnace does not hold a week's supply of materials, as was surmised in the picture of only seeing the following Monday the result of the previous Monday's charging. The total quantity it holds is as follows:—

Coke	210 tons
Ironstone	525 „
Limestone	131 „
	866 tons

which at a make of 450 tons per week would be emptied in $81\frac{1}{2}$ hours; so that what is put in on Monday morning will reach the hearth on Thursday afternoon, even at the rate of working of only 450 tons per week. But when it is considered that the furnace is constructed to produce 600 tons of iron per week, and with higher pressure of blast should do so, the period occupied would then only be 60 hours or only $2\frac{1}{2}$ days.

Now as to the natural laws which determine the quantity of coke with which a ton of iron can be made under the conditions

named. That there are such laws all must admit; but whether Mr. Bell has really found them all out is the question. No one has done more experimentally towards arriving at them, and bringing theory into harmony with practice; and his experiments have been most ably criticised by Mr. Gruner, who, on the data given by Mr. Bell and the assumption that his observations are correct and final, has reduced them with mathematical precision to formulæ from which (where the data are correct) there is no escape. Into these it would be out of place to go now; but there is one conclusion of Mr. Gruner's to which attention must be drawn, inasmuch as it bears materially on the present question. Mr. Bell's calculations have been based on the assumption that all the carbonic acid furnished by limestone in a blast furnace is converted into carbonic oxide before it leaves the furnace. He has stated in his Chemical Phenomena of Iron Smelting (page 111) that "it may be inferred that as carbonic acid, in an atmosphere of carbonic acid, is only sparingly given off at a full red heat, and carbonic acid commences to suffer decomposition at 752° to 932° Fahr., all the carbonic acid entering the furnace combined with lime leaves it as carbonic oxide:" in other words consumes 1·32 cwt. of carbon in the coke per ton of iron made. It is on this assumption Mr. Bell submits the following estimate of the minimum limits of consumption. He says very properly that 6·58 cwt. of carbon should be converted into carbonic acid; but improperly assumes that the carbonic acid of the limestone cannot give a direct addition thereto of 1·32 cwt. Assuming the possibility of this addition—and, by the way, Mr. Gruner proves Mr. Bell from his own results to be wrong in the contrary assumption, as will be seen by reference to Gordon's translation of Gruner's work (page 44)—the total carbon as carbonic acid possible would be 6·58+1·32=7·90 cwt.

Again Mr. Bell asserts that there cannot escape from the tunnel head of a furnace a mixture of gases containing less than 2 lb. of carbon as carbonic oxide for 1 lb. of carbon as carbonic acid. If this assertion be true, and it be not true that all the carbonic acid of the limestone is necessarily turned into carbonic oxide by the absorption of carbon, Mr. Bell's calculation of minimum consumption

of coke needs to be considerably modified. The figures submitted by him were as follows :—

	Cwt.
Carbon in CO_2 from Fe_2O_3 5·98, and carbon deposited 0·60 =	6·58
Minimum carbon possible as carbonic oxide . $2 \times 6·58$ =	13·16
Total carbon in escaping gases	19·74
Subtract carbon furnished by 11 cwt. of limestone . .	1·32
Leaving carbon furnished by coke to gases . . .	18·42
Add carbon furnished by coke to deposited carbon . .	0·60
Total carbon furnished by coke	19·02
Add ash, 8 per cent.	1·52
Total coke needed	20·54

Taking the extreme case of all the carbonic acid of the limestone escaping as such, we have as follows :—

	Cwt.
Carbon in CO_2 from Fe_2O_3 5·98, and carbon deposited 0·60 =	6·58
Carbon in CO_2 from 11 cwt. of limestone	1·32
Total carbon from above three sources, escaping as CO_2 .	7·90
Minimum carbon possible as carbonic oxide $2 \times 7·90$ =	15·80
Carbon furnished by coke and limestone to gases . .	23·70
Add carbon furnished by coke to deposited carbon . .	0·60
	24·30
Subtract carbon furnished by limestone	1·32
Total carbon furnished by coke	22·98
Add ash, 8 per cent.	1·83
Total coke needed	24·81

Between 20·54 cwt. (the estimate given by Mr. Bell on the assumption that all the carbonic acid of the limestone is turned into carbonic oxide by the absorption of 1·32 cwt. of carbon per ton of iron made) and 24·81 cwt. (the minimum consumption calculated on the supposition that all the carbonic acid evolved from the limestone may escape as such), any consumption should be possible according to the proportion of carbonic acid evolved therefrom undergoing such conversion into carbonic oxide; but the possibility of such a large fluctuation in the minimum based on such an assumption must surely throw grave doubts either on Mr. Bell's data or his mode of

employing them. Were this conversion of all the carbonic acid evolved from the limestone into carbonic oxide an inevitable consequence of introducing it in the raw state into the blast furnace, surely the calcining of limestone must offer the full advantage of saving 1·32 cwt. of carbon on Mr. Bell's estimate of minimum consumption of 19·02 cwt. of carbon (1·42 coke on 20·54) besides the fuel necessary to effect the calcination; but the result of Mr. Bell's observation as given in his Chemical Phenomena (page 338) is that "the economy of fuel in employing calcined limestone never quite amounts to that of the actual quantity required for burning it." Mr. Bell urges, as a reason for this alleged fact, that caustic lime absorbs carbonic acid rapidly at a red heat; but the reduction of the ironstone takes place far below a red heat, commencing, as Mr. Bell shows in his Chemical Phenomena (page 40) at 392°, and operating below a red heat in spite of any excess of carbonic acid in the escaping gases (see page 31 of same work). Carbon deposition also takes place about the same temperature as that at which reduction of the ore commences. At such temperatures the influence of generated carbonic acid on caustic lime must be very feeble indeed; whilst the fact remains that the total carbonic acid in the escaping gases must be less by the quantity driven off by calcination of limestone outside the furnace. He, Mr. Cochrane, therefore could not accept Mr. Bell's conclusion on this point, and believed that further investigation will reveal an error, the existence of which Mr. Gruner in his able criticisms has been the first to indicate.

As regards the escape of gas from the sides of a furnace, and having special regard to the explanation of the explosion which was attributed in the paper to this cause, on further investigation this judgment has been confirmed by the occurrence of similar explosions which have taken place whilst the furnace is in regular work; and that they result from a still further escape of gas than what has been indicated. In the construction of the furnaces a clear space has been left between the linings and the external brickwork, varying from $1\frac{1}{2}$ in. around the boshes to $\frac{3}{4}$ in. or $\frac{1}{2}$ in. at the top, to allow for expansion. There was no doubt that owing to the destructive action of the scaffolds over 1871-1872 the linings have

been damaged, and gas passes up at the back of the linings, hot and rich in carbonic oxide, and passing outwards underneath the filling plates or flooring at the top of the furnace occasionally exploded. Such a loss was unquestionably going on, and he felt assured accounted in some measure for the inability in 1873 and subsequently to restore the former healthy working of Nos. 3 and 4 furnaces, notwithstanding they were favoured with the higher pressure of blast indicated. Add to this the altered and deteriorated form of boshes due to grooves and caverns excavated by irregular descent of materials and the breaking off of scaffolds, and the necessarily diverted and localised action of heat, instead of being diffused over the entire area of the boshes—and I think we have abundant explanation of the bad working of Nos. 3 and 4 furnaces. To save 8 cwt. of coke from 26·5 cwt. by simple reduction of temperature of escaping gases, as they existed in a furnace of 20,000 cub. ft. capacity and employing blast at 1000°, he (Mr. Cochrane) admitted to have been an early dream of possibilities, and it is nowhere now alleged that it is possible. But what was surmised could be accomplished by that means alone, has at any rate been nearly accomplished by the combined effects of increase of temperature of blast and extra capacity of furnace: each effect telling clearly, to the writer's mind, according to definite curves of saving, and each independently of the other. It is not denied that there may be other causes to operate against the good working of a furnace, than that of reduction of effective capacity; and certainly the case named in the paper, of Nos. 3 and 4 furnaces, of gases escaping before they have done their work—and the one Mr. Bell has named, of an exceptional quality of coke—are illustrations of other causes; but such exceptions are obvious. All circumstances being alike as to quality of materials &c., save and except the capacity of a furnace, it must be obvious that a large furnace may become contracted in its working capacity; and that if pressure of blast be too small for the large furnace and just enough for the small, the large one will infallibly be reduced in effective capacity to that of the smaller, with all the disadvantages of a self-formed interior, constantly changing in shape and producing untold irregularities in working. In the case of the furnace of

33,140 cub. ft. capacity working at 21·17 cwt., exactly as had done one of 20,624 cub. ft. under the same conditions, it is clear that the effective capacity of the larger furnace was practically reduced to that of the smaller, because there were apparently no other disturbing causes; the difference of 12,516 cub. ft. represents therefore the ineffective capacity.

In reference to the results recorded by Mr. Samuelson, he was under the impression when he referred to them that the ironstone used was from the same mines from which the supply was procured for the Ormesby Iron Works, and on enquiry this has been confirmed, showing that Mr. Bell was mistaken in supposing that Mr. Samuelson's results were obtained from richer ores.

There is another point to which Mr. Bell referred in his experiments on temperature of escaping gases, which needs consideration. He replaced the normal load of the furnace by flints and blast-furnace cinder, weight for weight, and thus excluded the possibility of chemical action on the ironstone, causing thereby a reduction of temperature due to the absence of the chemical action which takes place when the furnace is supplied with ironstone. The usual temperature of the escaping gases, when fed as in regular work with ironstone, was stated to be 782° Fahr. In 40 minutes flints and blast-furnace cinder lowered this temperature to 560°, and in $3\frac{1}{2}$ hours to 464°. On recharging ironstone, the temperature of the escaping gases rose in one hour to 500°, in two hours to 531°, and in three hours to 700°; thus establishing the fact that at the temperature at which reduction of ironstone is active there is a development of sensible heat as the balance of chemical reaction of the gases on the ironstone. To absorb sensible heat, from whatever source it was derived, has been the writer's object in increasing the capacity of the blast furnace; and he confidently claims to have established in furnaces of large capacity (in good working order) the existence of another zone or region, in addition to those described by Mr. Bell, in which no chemical action takes place at all, and nothing occurs but the absorbing of sensible heat.

With reference to the expression "ultimate capacity of blast furnaces," which had been objected to, it was clear that this

must not be understood too literally, because as a mere question of engineering it would of course be possible to add another 40,000 cub. ft. capacity to the 40,000 cub. ft. that had already been reached in the largest furnace described. But it would not be worth doing so, having regard to the commercial limits, within which the best results could be obtained. Combining theory with practice, he had endeavoured to show what should be the ultimate capacity of blast furnaces, as arrived at in his own experience; the results obtained were not of general application, but were limited to the conditions of the Cleveland district. The paper dealt with a region which was mainly outside that of chemical action, and in which he maintained that useful work was done independent of chemical action. The assertion by Mr. Bell, that the chemical action would follow up any increase of height in the furnace, he considered had been disproved entirely by the working of the large furnace referred to in the paper; for in that furnace he had been dealing with a region containing 10,000 cub. ft. in which there was very little chemical action—in which in fact the materials were only being prepared for chemical action. Presuming therefore that the chemical action had been conducted properly down below, the temperature of the gas escaping at the furnace top became the pulse of the furnace, showing any neglect to fill properly in a rise of temperature, and the existence of any scaffolding below by a similar rise; and in the present paper he had accordingly endeavoured to deal with the mechanical part of the subject, without entering into the chemical part.

As to the suggestion that two furnaces, each of half the capacity of a third, would work with equally good results if put each to do half the work of the third, he could only say that in practice he had never found the smaller furnaces giving such good results as were obtained from the larger ones. In the smaller furnaces there was greater facility for the gases passing up through the materials; and they would consequently escape from the furnace at a higher temperature than in larger furnaces, so that an equally good result could not be got out of the smaller furnaces. On this account he considered that, with the extent of range in the capacity

of the furnaces referred to by Mr. Bell, the larger of those furnaces ought to have worked better than the smaller.

The PRESIDENT remarked that there seemed at present much diversity of opinion in the discussion of this subject, and he hoped the conflicting views would be followed up by still further researches, until the correctness of one or the other should be established. It appeared to him however that one observation, in addition to what had already been advanced, was worthy of some little attention, and that was that this question had not been considered as much as he thought it ought to have been from a mechanical point of view. Much attention had been directed to the chemical action, but it appeared to him that to a considerable extent the solution of this question depended upon mechanical considerations; it was really a question of maximum and minimum. It could not be said that small furnaces gave the best result, nor could it be said that large furnaces gave the best result, because of the mechanical crushing power of the absolute weight put into the furnace. If a huge weight of materials were piled above a certain height, it was quite clear that the weaker of those materials must crush; in such a case the furnace would not merely scaffold, but would plug itself, and there would be a great difficulty in the blast getting through with that freedom which was essential to the production of a high intensity of heat. He had witnessed this in many other cases besides blast furnaces, and in his opinion there was a limit in every case to the magnitude and particularly to the height at which blast furnaces could be worked for producing the maximum effect. If a high furnace were employed where the materials were so weak as to crush, and where they consequently interfered with the production of proper blast or with the maintenance of the necessary intensity of heat, then it was unquestionable that the effect must be below the maximum, although it might not be so low as the minimum; and he wished that, in addition to the chemical considerations, a little more information had been given in the paper and discussion as to the experience with regard to the mechanical conditions which obtained

in the large furnaces; both should be considered, he was convinced, in a case of this kind. They were very much indebted both to Mr. Cochrane and Mr. Bell for their great labours in connection with blast-furnace economy, and to Mr. Cochrane for the very interesting results he had brought forward in his paper. He was sure the meeting would accord to him a cordial vote of thanks for the paper, and for the additional information he had given in the present discussion.

The vote of thanks was passed.

The following paper was then read:—

ON THE MODE OF ERECTION OF THE LARGE IRON GIRDER RAILWAY BRIDGE OVER THE RIVER DAL IN SWEDEN.

By Mr. EDWARD HUTCHINSON, of Bournemouth, (late of Darlington.)

The Bridge, the peculiar mode of the Erection of which it is the purpose of this paper to describe, is one of a series constructed for the Bergslagernas Railway Co. of Sweden, by the Skerne Iron Works Co., of Darlington. The main line of this railway connects the East Coast of Sweden at Gefle with the West Coast at Gothenburg, and runs for the most part through a densely wooded and thinly populated country. The railway crosses the river Dal, the most important stream in Sweden, about ten miles to the west of the town of Fahlun. At this point the river, elsewhere of much greater width, is about 400 feet wide from bank to bank, and is a deep and rapidly flowing stream, forming a cataract almost immediately below the site of the railway bridge.

The bridge is for a single line of railway, and is formed of three spans; the two side spans being 80 ft. each, and the centre span 208 ft. clear opening, with 40 ft. height from the water, as shown in Figs. 1 and 2, Plate 1. The abutments are of granite masonry, and are founded upon the solid rock. The two piers are also bedded upon the granite rock which forms the river bed, and for a height of about 15 ft. above low water level are constructed of granite masonry. Above this level the piers consist each of two square columns, each 8 ft. square, constructed of cast-iron plates bolted together at the angles and the horizontal joints, and filled in with brickwork in cement.

The girders for the side spans are formed with a double system of bracing, and are 10 ft. 6 in. depth; the top and bottom booms, which are of similar section, are composed of plate and angle iron, as shown in the enlarged transverse section in Fig. 11, Plate 4,

and the bracing ties and struts are of T iron of varying section. These girders do not rest directly upon the piers, but are supported by cross bearers fixed between the main girders of the centre span at the height shown in the general elevation of the bridge in Fig. 1. The rail bearers are level with the top flanges of these girders, so that the rail level is 3 ft. 10 in. below the top of the main girders.

The main girders, which are fixed 17 ft. apart centre to centre, are also formed of a double system of bracing, and are 19 ft. 10 in. depth and 2 ft. 6 in. width on the flange and 214 ft. 5 in. length of bearing. The top and bottom booms are built up of plates and angle iron, and have a double web of angle and plate, to which the bracing bars are riveted, as shown in the enlarged transverse section in Fig. 10, Plate 4. The bracing is composed in part of H iron, in part of angles and flats riveted, and in part of T or L iron. At each alternate intersection of the bracing, a vertical member is introduced supporting the cross girders, which are built of angle and T iron, and are 2 ft. depth. Below each cross girder is a system of vertical diagonal bracing; and horizontal bracing, of which the cross girders form the compression members, runs from end to end of the centre span.

The girder bed-plates are bedded upon the brickwork, and are provided with adjusting apparatus at each end, and with expansion rollers at one end only. These are shown enlarged in Figs. 12 to 14, Plate 4. The stationary bed-plates are of cast iron, with a steel adjusting pin; but those used in connection with the expansion rollers, as well as the rollers themselves, and the adjusting pins, are of crucible cast steel.

The wrought iron of which the superstructure of the bridge is composed was guaranteed by the contractors to stand the following tests. For the side spans all plates to bear a load of 20 tons per sq. in. before fracture, and all angle and bar iron 22 tons; in each case showing an elongation of 10 per cent. before fracture. For the main span the plates were to bear a load of 21 tons per sq. in. before fracture, and the angle and bar iron 23 tons. The plates to show an elongation of 10 per cent., and the angles and

bars an elongation of 15 per cent., before fracture. The rolled joists, rivet iron, &c., were also subjected to special tests. The whole of the ironwork was in the first place put together in the contractor's yard at Darlington, and subjected to various tests. It was then taken down and transported to the site of erection in small pieces.

Owing to the character of the stream to be spanned by the bridge, none of the ordinary modes of fixing girders of this size seemed quite feasible. The erection of the side spans, of 80 ft. each, presented of course no difficulty; and, if desired, in the case of these spans, staging could easily be erected from the abutment to the pier, as shown. Between the piers however, 208 ft. apart, it seemed impossible to get the smallest prop or support of any kind. During the summer season, immense quantities of pine timber, either in the form of rafts or loose masses, were continually floating down the river, and would quickly have carried away any staging it would have been practicable to erect. In the winter the ice presented a difficulty of equal or greater magnitude, and owing to the proximity of the falls just below the bridge, the ice never became so thick as to afford a safe platform upon which to work.

Under these circumstances, the plan of rolling the girders over the piers was naturally the first to suggest itself, and did not at first appear to present any unusual difficulty. It will however be found that in most cases where this plan has been successfully adopted, the superstructure of the bridge has been composed of a number of spans of equal or nearly equal length; and where this uniformity exists, it is not difficult, even in the case of non-continuous girders, to connect two or more spans together in such a way that a whole span length may be safely projected over the pier. Nor does the length of span affect the question much, as the girders are necessarily of a depth and strength proportionate to their span. But when a pair of girders have to be projected a clear 208 ft., with only a pair of 80 ft. girders to balance them, the conditions are entirely altered, and although not impossible, it would not be by any means easy of accomplishment. To meet the difficulty in the case of the Dal bridge various schemes were proposed.

The original plan intended by Lieutenant Almquist, the Engineer for the Bergslagernas Railway, and to whose designs the bridge was constructed, consisted of a staging carried by chains suspended between the piers; but when worked out in detail, this plan promised to be a most tedious and costly one, and moreover would have necessitated the greatest care in its adoption, in order to avoid damage to the piers. It would in fact have been almost equivalent to building a suspension bridge of equal strength to that of the permanent structure.

It was also proposed to build all the girders on one side of the river, and to attach them together in the order they occupy permanently in the bridge; then, properly counterweighted, to launch them in the usual way. This plan offered some advantages, but connections of great strength would have been required; besides which, many portions of the girders would have been subjected to severe abnormal strains—an objection which hardly applies at all to the mode of erection ultimately adopted.

Timber being plentiful and cheap in the neighbourhood of the bridge, various forms of projecting staging formed of this material were also contemplated; but when worked out in detail, none of them seemed to be altogether unobjectionable. Before the method to be adopted was finally decided upon, the staging between the abutments and the piers, as well as the struts projecting from the piers, were provided by the Railway Co., it being understood that the girders would be fixed by some sort of rolling operation.

It was however ultimately decided to adopt the following plan. Upon the timber staging already provided, the 80 ft. girders were riveted up, not in position shown in the finished elevation, Fig. 1, but with their bottom flanges level with those of the main centre girders, as shown in Figs. 3, 4, and 6, Plates 2 and 3, being temporarily braced together by means of timber struts and the permanent ties, as shown in Fig. 5, at a distance apart corresponding to that of the main centre girders. Four strong ties were then fixed between the top of the end of the main girders and a point near the centre of the 80 ft. girders. These ties are shown shaded in Fig. 6, at A, C, and sections of them in Fig. 7, at A, B, C, D.

They are all composed of bars ultimately forming portions of the permanent structure, such as longitudinal rail bearers, bracing struts, &c. Special connections however had to be provided, and about 12 tons of material, of various sections, was used throughout for this purpose.

The bottom boom of the 80 ft. girders being of insufficient section to stand the compressive strain to which it would be subjected during the process of erection, the strain had to be distributed by means of the compression struts E, Fig. 6, shown in section at E F in Fig. 7, these also being composed of parts of the permanent bridge.

The ends of the main girders being securely braced and tied to the 80 ft. girders, as above described, it became necessary to distribute the counterweight in such a way that no undue strain should come upon any part of the 80 ft. girders, and in addition to this it was found necessary to strengthen them a little at the centre, near the point of attachment of ties.

The diagram, Fig. 4, Plate 2, shows how the counterweight, composed chiefly of rails, was distributed: 47 tons being placed at the extreme ends of girders, 18 tons near the point of attachment of ties, and 28 tons in the girders and ties themselves, making a total of 93 tons. The weight of the half main span, with a fair allowance for tools &c., was ascertained to be 100 tons, and the distance of the centre of gravity from bearing point on pier 57·2 ft., as shown in Fig. 4. Care was taken that none of the weight came upon the props that projected a few feet outwards from the piers, as shown in the general elevation, Fig. 3.

All being made secure, the process of projecting out the main centre girders was commenced from both piers simultaneously. Each member of the girder was fixed in position in nearly the same form in which it left the works—that is, no further riveting was done until each piece was in position. As the riveting up of the main girders proceeded, the cross girders which had been riveted up at the works were fixed, as well as the rail bearers and such parts of the main horizontal bracing as seemed necessary to give stability to the work. But the main flange plates, as adding greatly to the

overhanging weight, without giving any additional strength, were not put on until the girder was in other respects complete.

The weight of the heaviest piece fixed at one operation did not exceed 25 cwt. No special provision in the form of staging for the workmen was provided, planks temporarily laid across the transverse bearers or rail girders being found sufficient for the purpose; but it was deemed prudent by the workmen to test the stability of the girder occasionally by running out a small truck load of material weighing about 5 tons to the end of the girder. In the first instance portable cranes were used in moving and fixing the various parts; but better progress was found to be made with long-jibbed Scotch derrick-cranes, and the use of the portable cranes was abandoned.

As the girders during erection rested solidly on the piers and not upon the rollers, great care had to be exercised in order to fix each half in its correct position as to length. This was done by means of a wire stretched across the river, the operation being repeated several times at various temperatures. When the closing piece came to be fixed in position it did not fill the space by about an inch; but the following day, under the influence of a bright sun, this gap disappeared, and the closing portions had to be driven into their places.

The bridge was erected during the winter season, and the cold at times was so severe that operations had to be entirely suspended; the days too were very short. From these combined causes the erection occupied a much longer time than it otherwise would have done, namely about five months. When, the main girders having been completed, the temporary ties were cut away, there was only a slight and hardly appreciable deflection at the centre of the main span. No accident of any kind happened in carrying out the work.

In conclusion, the writer, whilst not wishing to take any credit to himself as having accomplished any very important work, at the same time desires to recommend to any who are interested in bridge building, the plan here described for cases where the girders are of considerable length, and staging impracticable.

SUPPLEMENT.

The sectional areas of the top and bottom booms of the main girders (which are equal) are 88·5 sq. in. at the centre and 32·2 sq. in. at the ends; the centre having six plates $30 \times \frac{3}{8}$ in. each, and the ends only one plate $30 \times \frac{3}{8}$ in. During erection these plates were omitted, leaving the sectional area only 21·0 sq. in. throughout each of the booms.

During erection the only abnormal strain was a compression strain upon the bottom of the small girders at E F, Fig. 6. The sectional area of this is only 16·37 sq. in., and as the strain in compression required about 25 sq. in., the additional area was obtained by putting on two channel-iron bars of 12·25 sq. in. total area, one on each side, as shown at E F in Figs. 6 and 7, thus making a total sectional area of 28·62 sq. in.

The sectional area of each of the temporary ties A C was 27·17 sq. in., being composed of one bar of **I** iron and two pairs of bars of channel iron. In the calculations for erection of the bridge no part was subjected to a greater strain than 5 tons per sq. in. compression or tension.

In the calculation of the counterbalance weight 80 tons only has to be taken for the weight of each half of the main girders during erection, instead of 100 tons the total finished weight, on account of all the top and bottom flange plates and much of the bracing being omitted until the junction of the two halves in the centre was effected. The calculation for the counterbalance was as follows :—

	Tons.	Ft.		Total.
HALF MAIN GIRDERS	80	× 57·2	=	4576
COUNTERBALANCE				
Side Girders	24	× 46·6	= 1118·4	
End Weights	23	× 83·4	= 1918·2	
	12	× 86·0	= 1032·0	
	12	× 80·8	= 969·6	
Middle Weights	6	× 36·8	= 220·8	
	4	× 44·0	= 176·0	
	4	× 38·8	= 155·2	
	4	× 33·8	= 135·2	
Ties	4	× 18·5	= 74·0	5799

As to the cost of erection, this is considered to have been about the same as a fair average of such work erected by any of the ordinary methods. It is difficult however to make a fair comparison, as so much depends upon the distance from home, cost of getting materials and tools to the spot, season and weather, &c. The labour in putting together, riveting &c., was little more than it would have been on staging, and the chief difference in cost would be that between the temporary iron ties &c. and wood staging.

Mr. S. Z. LLOYD enquired what was the additional strength which was required in the lower flange of the girders in this mode of erecting a span of those dimensions, over what would be required in erecting it upon a stage in the ordinary manner; as the lower boom, which was in tension when the bridge was completed, was in compression during the erection, additional material would have probably to be provided to meet that case. He asked whether calculations had been made as to the additional material required in the span for that reason, or whether the design was considered sufficiently strong without such addition.

Mr. JEREMIAH HEAD observed that the sections at the top and bottom of the girder appeared to be the same, and they would therefore bear reversing. The bottom section which was in tension must be considered as weakened in proportion to the area of the rivet holes at each joint. The top was not affected in the same way, inasmuch as the rivets replacing the iron removed there took their share of the compression. The greater strain which wrought iron in tension would bear as compared with when in compression was thus equalised in the finished structure.

Mr. J. PLATT remarked it had been mentioned that some of the top and bottom plates were left off till the bridge was joined up in the centre, so as to reduce the weight during erection; the bridge during erection had simply to carry its own weight, without any load.

Mr. E. A. COWPER asked for the dimensions of the sections, the details of which it was desirable should be given. It struck him however that the girders would be strong enough to carry their own weight for half the length of the bridge, seeing that the bridge was strong enough to carry a railway.

The PRESIDENT observed that some bridges of similar kind in America, which had been subjected to interferences of atmosphere, had been reported on by Capt. Galton.

Capt. GALTON considered the present communication a very interesting one, as showing a new way of erecting a bridge; and it would be very interesting to know what the cost of this method was, so as to compare the amount of labour expended and the extra material required with the cost of erecting by staging, because it was quite clear that in many cases of Indian railways such a mode of construction of a bridge might be found very valuable. As regarded the strains, of course the bridge during the construction was in a totally different condition from that which it must be in when it had to bear its load; it was not originally formed, he apprehended, for the purpose of resisting those new strains. He should be glad for more particulars to be given as to the strains to which the girders were subjected when in the process of erecting, and those to which they were subjected after the bridge had been erected. In addition to the cost of labour and materials he should also like to know the number of men employed, and other particulars, so that a calculation might be formed as to the cost of erecting a bridge in this manner, to afford a comparison with the cost of other methods of putting the work together, which could not be estimated from a mere statement of the weight of materials employed.

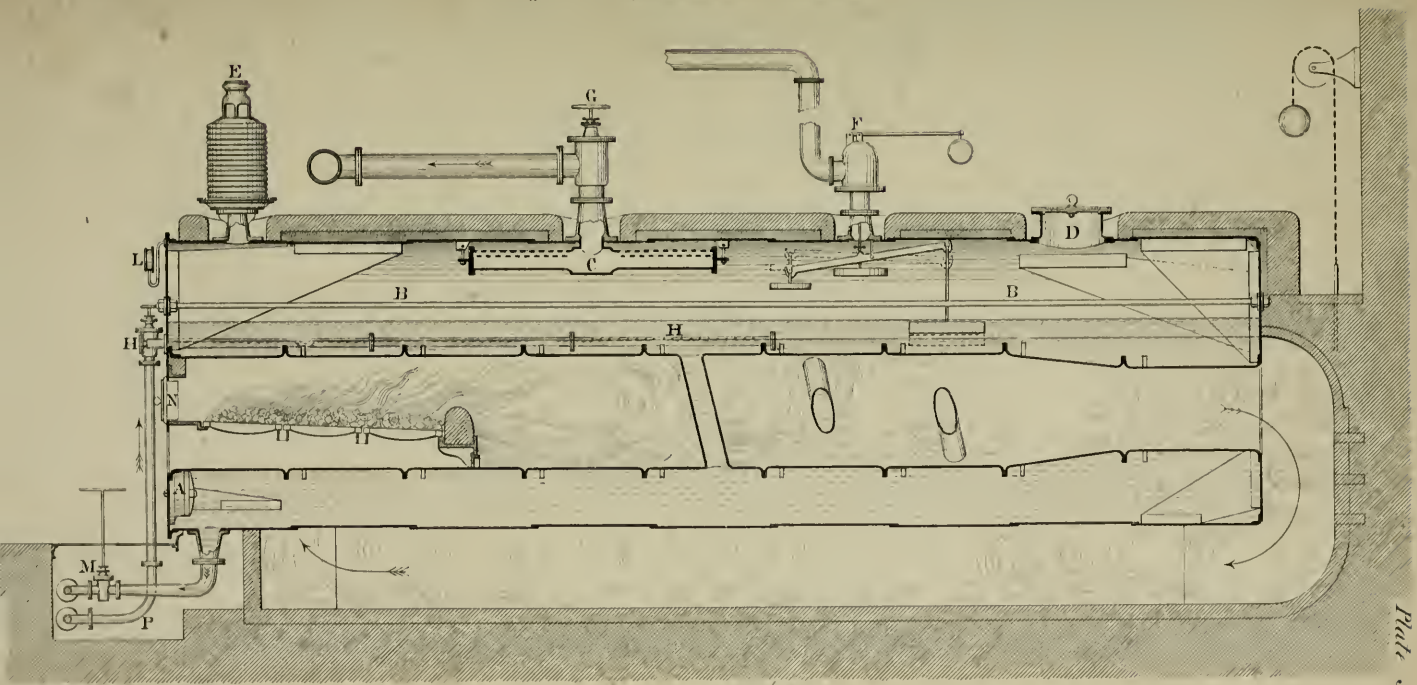
Mr. F. J. BRAMWELL referred to the specimen bridge built by the elder Brunel on the grounds of the Thames tunnel at Rotherhithe. This specimen consisted of a pier and of the half of an elliptical arch on the one side and about a quarter of a similar arch on the other. These arches were of considerable span probably 60 ft., they were constructed without any centering, simply of brick in cement bonded with hoop iron. From the end of the smaller section of the arch was suspended an immense mass of iron to balance the weight of the half arch on the other side.

The PRESIDENT, in proposing the usual vote of thanks for the paper, observed that it contained very important facts, and the subject had been dealt with in a very clear and unbiassed manner. He thought the author had brought before the Institution something which admitted of application, as Capt. Galton had said, under a great variety of circumstances and in many other places. He proposed that the vote of thanks should be accompanied by a request to the author to supplement the paper with the additional information which had been asked for in the discussion.

The vote of thanks was passed.

The Meeting then terminated. In the evening a number of the Members dined together in celebration of the Twenty-ninth Anniversary of the Institution.

Fig 1. *Longitudinal Section.*



(Proceedings Inst. M.E. 1876)

Scale 1/60th

Ins. 12 0 5 10 15 20 25 30 Feet

Plate 5.

LANCASHIRE BOILER.

Plate 6.

Fig. 2. *End Elevation.*

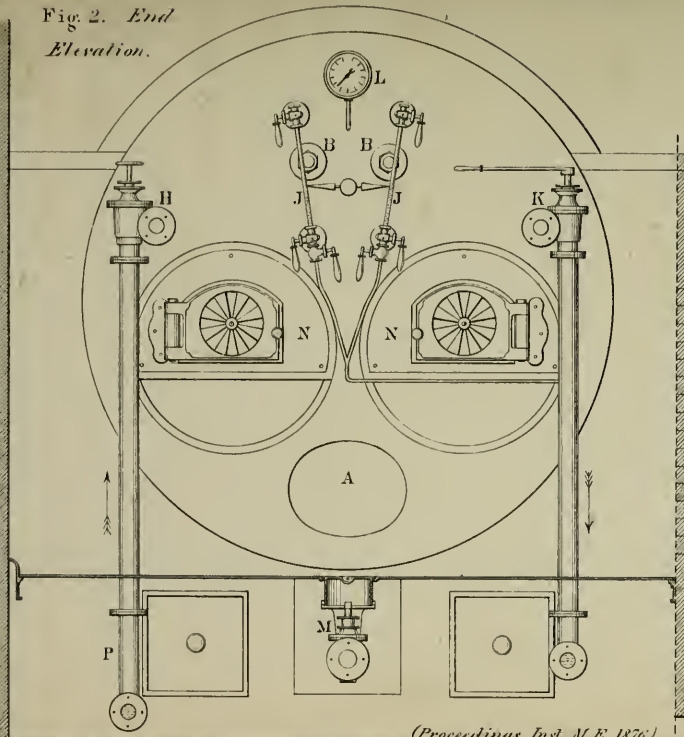
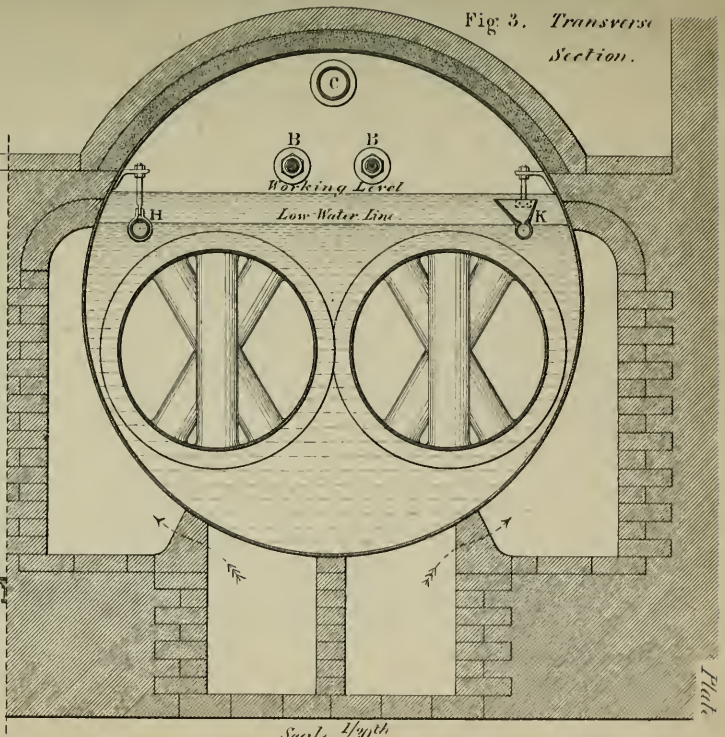


Fig. 3. *Transverse Section.*



(Proceedings Inst. M.E. 1876.)

Scale 1/20th.

Ins. 12 6 0 1 2 3 4 5 6 7 Ft.

Plate 6.

LANCASHIRE BOILER.

Grooved End Plate.

Fig. 4. *Inside Elevation.*

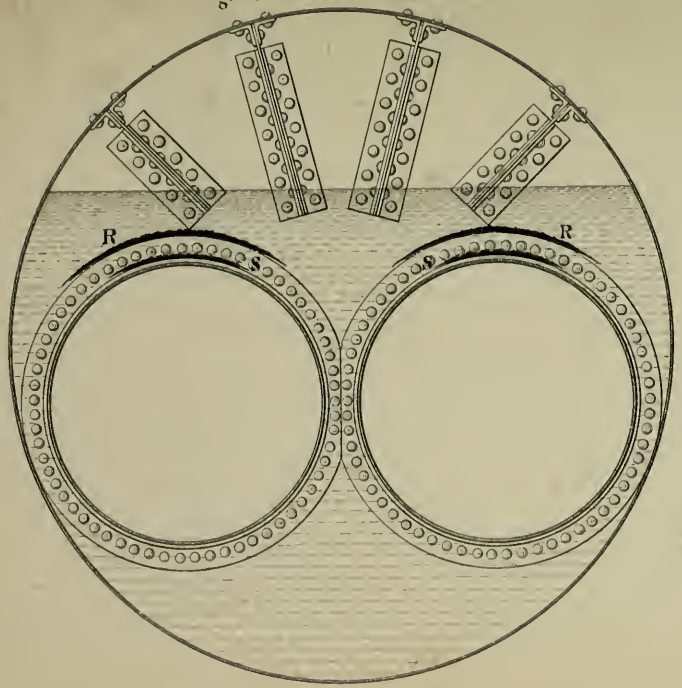
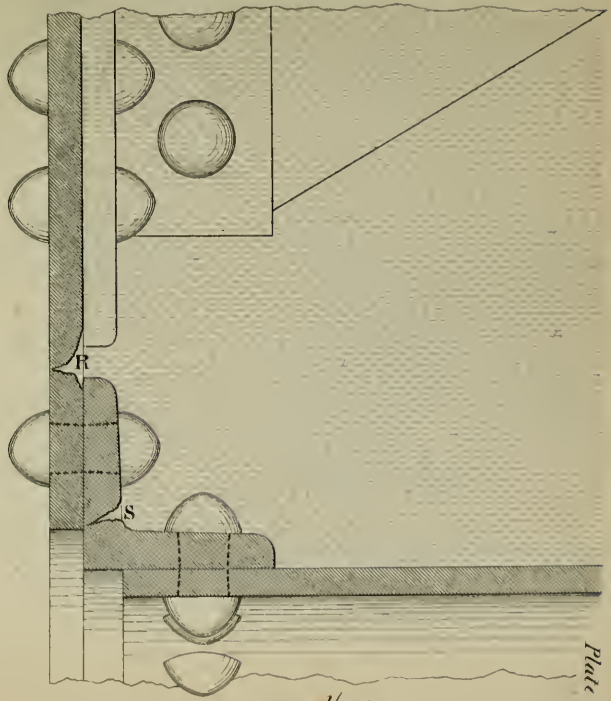


Fig. 5. *Longitudinal Section.*



(*Proceedings Inst. M. E. 1876*)

Scale 1/24th

Scale 1/3rd

Plate 7.

LANCASHIRE BOILER.

Ring Seams for Furnace-Tubes.

Fig. 6. *Adamson Flanged Seam.*

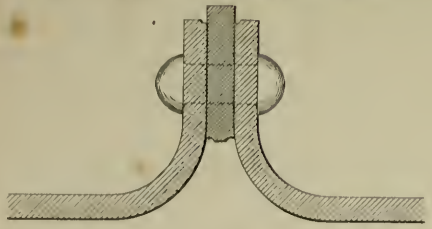


Fig. 8. *Bowling Hoop.*

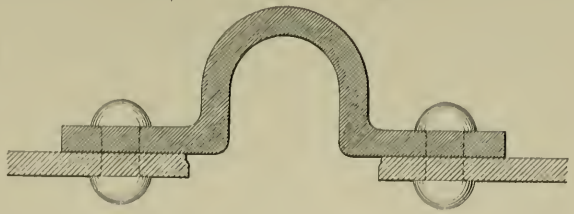


Fig. 7. T *Seam.*

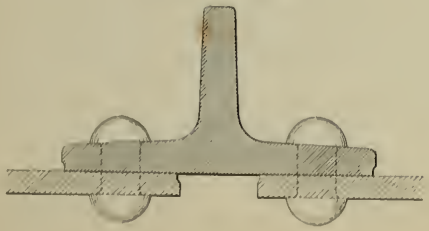
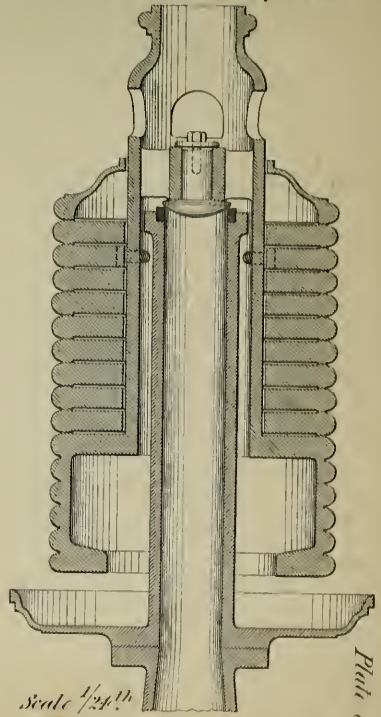


Fig. 9. *Bolton Steel Hoop.*

(Proceedings Inst. M.E. 1876)

Scale 1/3rd

Fig. 10. *Cowburn Safety Valve.*

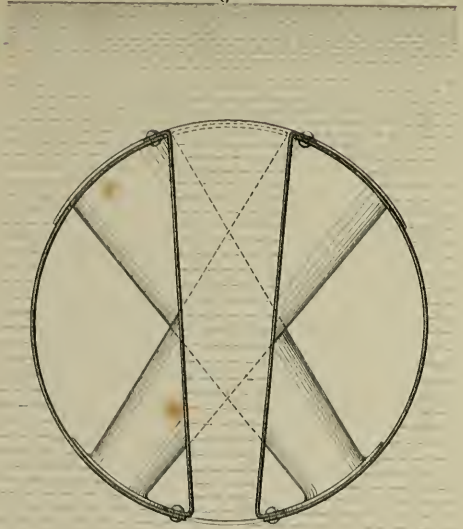


Scale 1/24th

Plate 8.

Galloway Water Pipes.

Fig. 11.



Petrie Water Pockets.

Fig. 12.

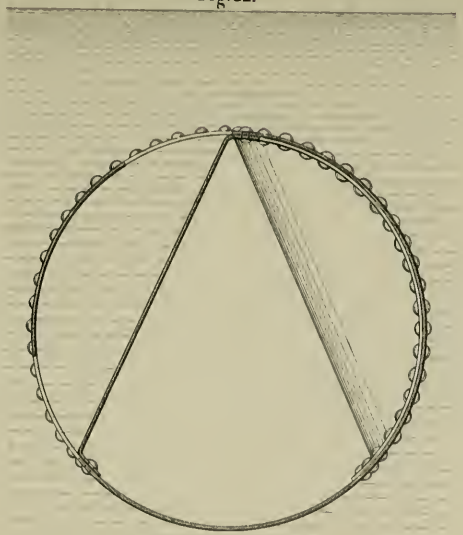
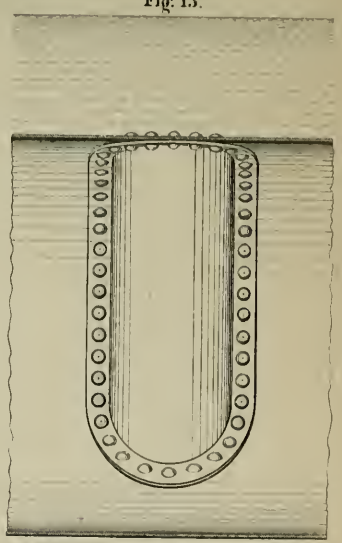


Fig. 13.



(Proceedings Inst. M.E. 1876)

Scale 1/16th

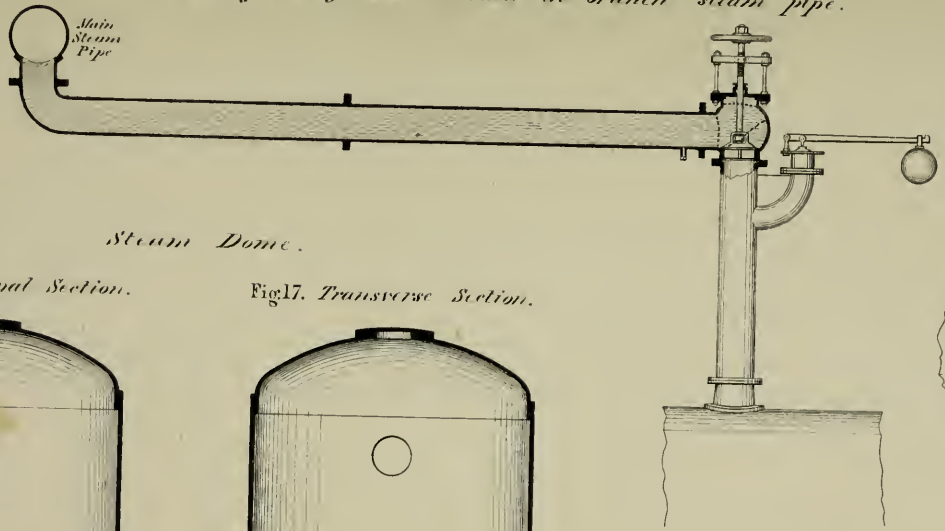
Ins. 12 6 0 1 2 3 Feet.

Plate 9.

BOILER.

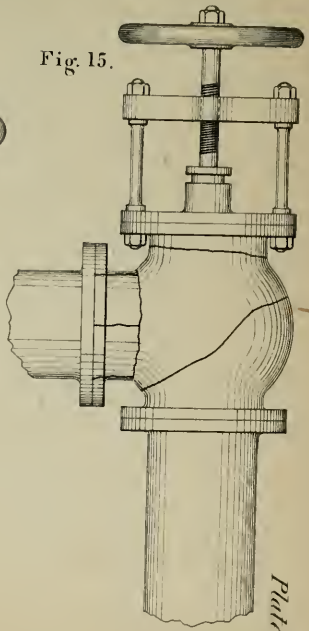
Fractured Junction Valve-Box through lodgment of water in branch steam pipe.

Fig. 14.



Scale 1/48th

Fig. 15.



Scale 1/16th.

Fig. 16. *Longitudinal Section.*

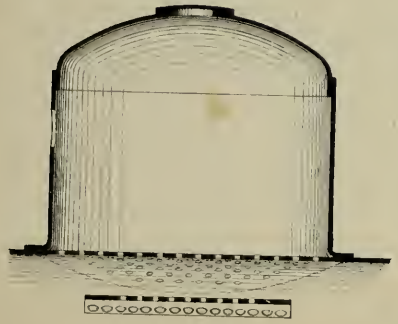
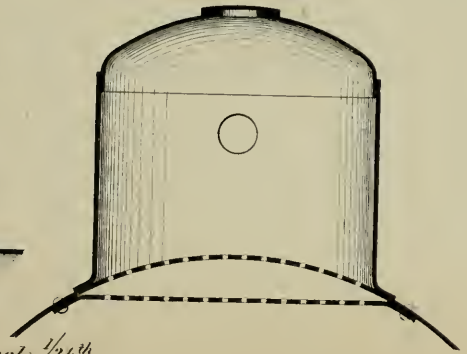


Fig. 17. *Transverse Section.*

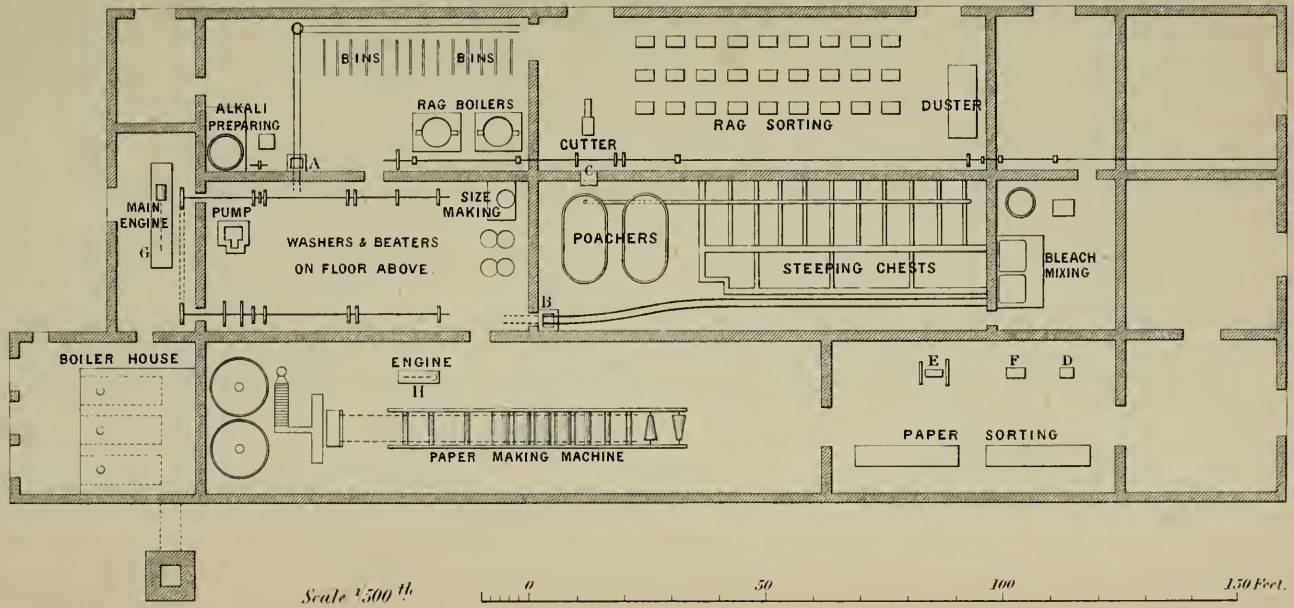


Scale 1/24th

(*Proceedings Inst. M.E. 1876.*)

Ogi Paper Mill.

Fig. 1. *General Plan of Mill*



(*Proceedings Inst. M. E. 1876.*)

Plate II.

Ogi Paper Mill.

Fig. 2. *Longitudinal Section of Mill*

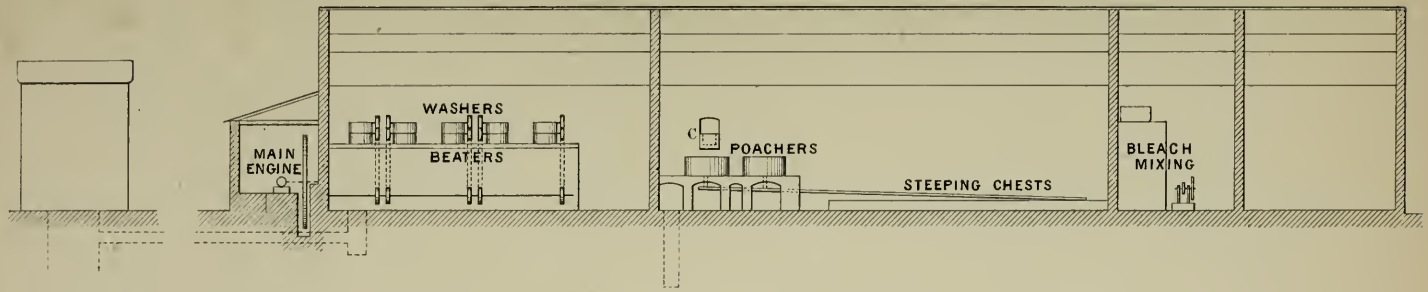


Fig. 4. *Plan of Upper Floor.*

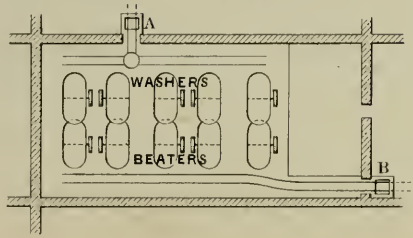


Fig. 3. *Transverse Section.*

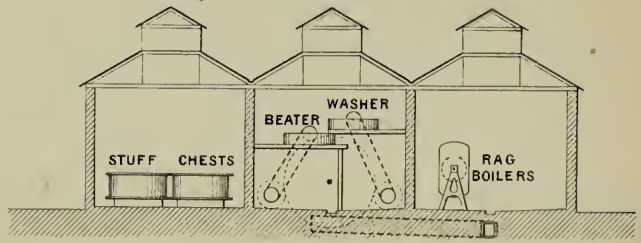


Plate 12.

(*Proceedings Inst. M. E. 1876.*)

Scale 1/500 th

0 10 20 30 40 50 60 70 80 90 100 Feet.

Rag Boiler.

Fig. 5. *Vertical Section.*

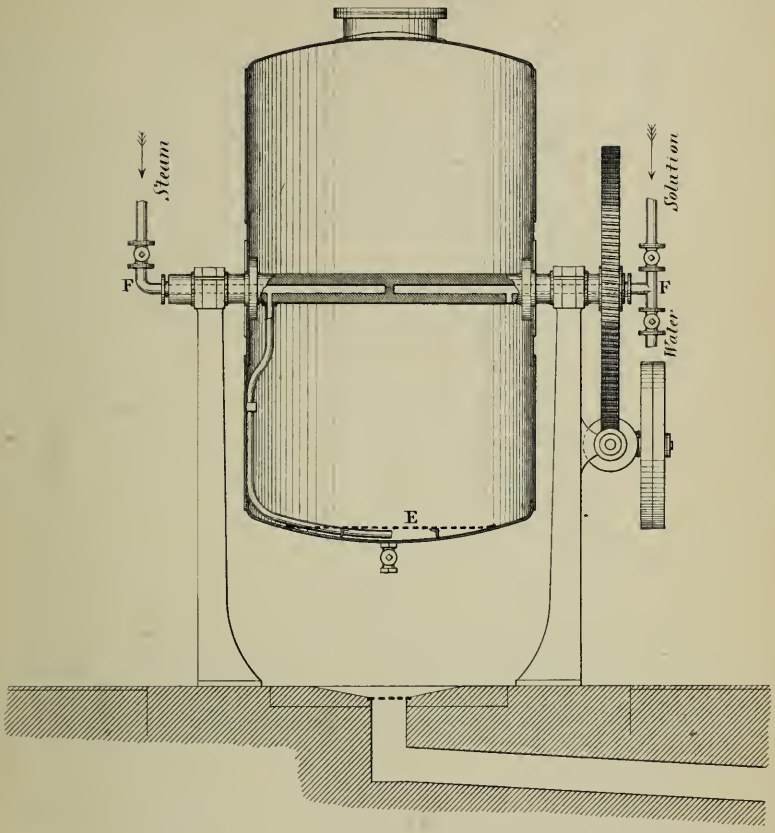
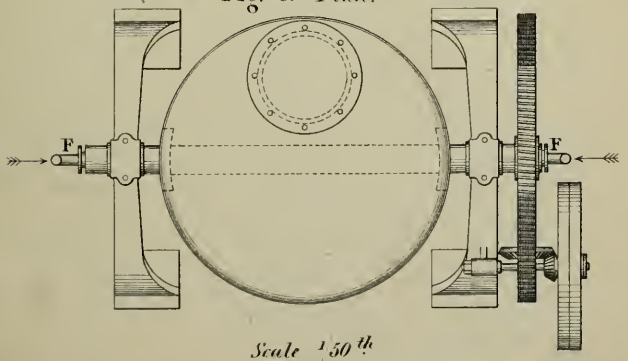


Fig. 6. *Plan.*



Scale 1/50th

Ins 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

PAPER MILL.

Plate 14.

Alkali Mixer.

Fig 7. *Transverse Section.*

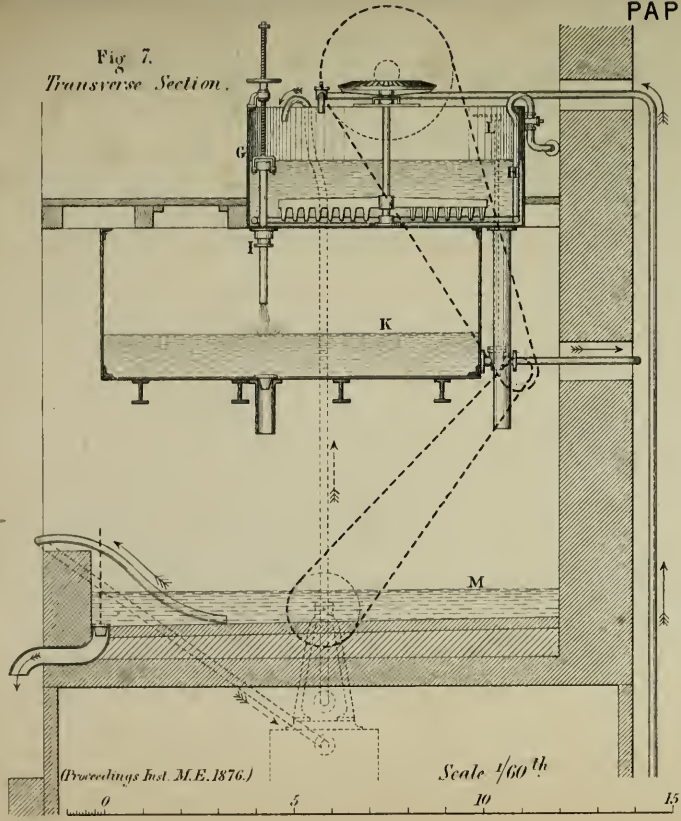


Fig 8. *Elevation.*

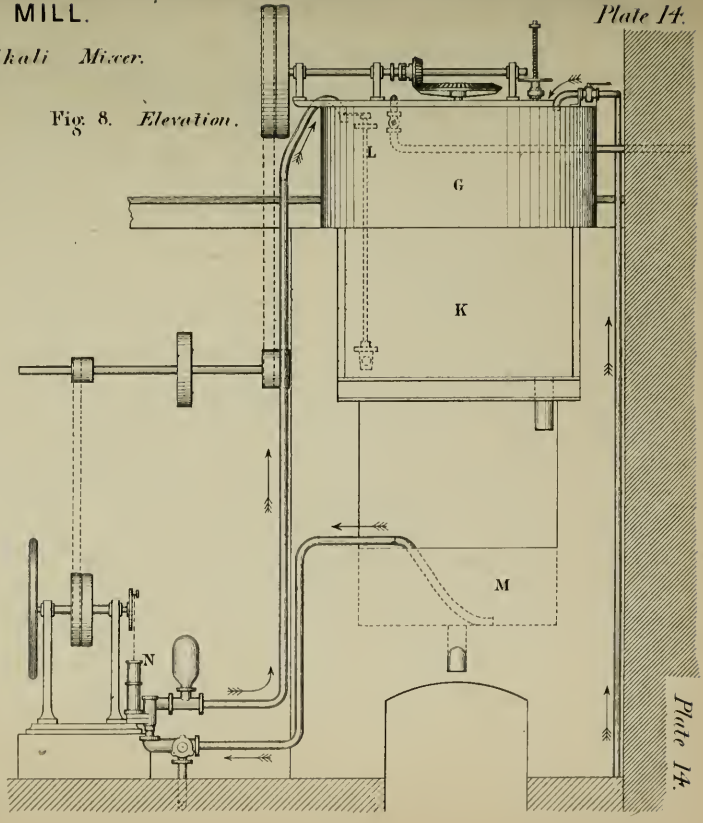


Plate 14.

Washer and Beater.

Fig. 9. *Washer.*

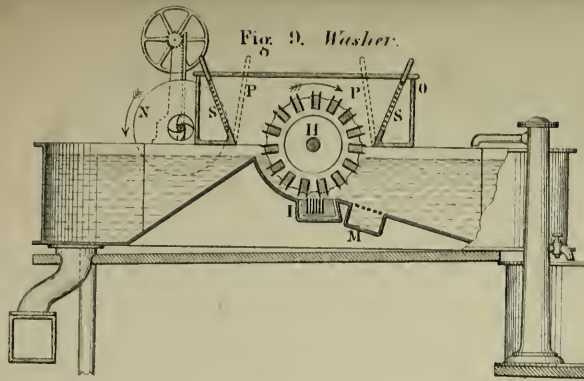


Fig. 11. *Beater.*

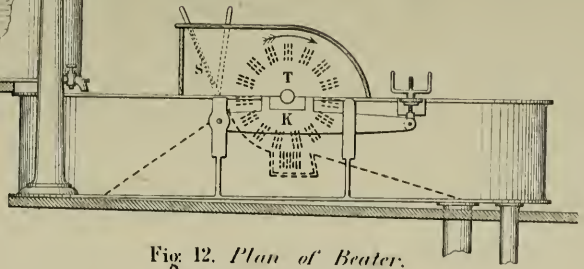


Fig. 13.
Transverse Section of Beater.

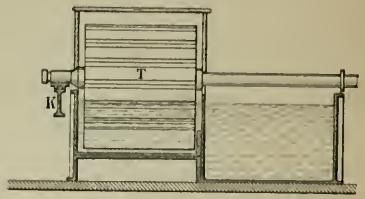


Fig. 10. *Plan of Washer.*

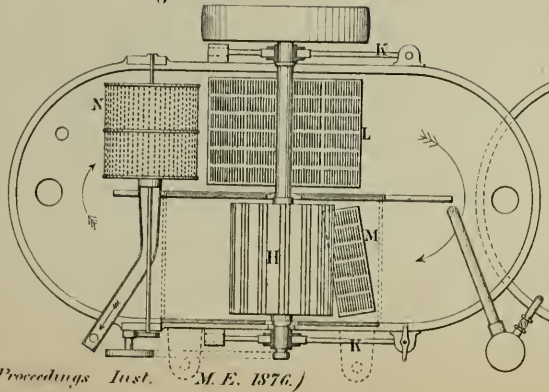


Fig. 12. *Plan of Beater.*

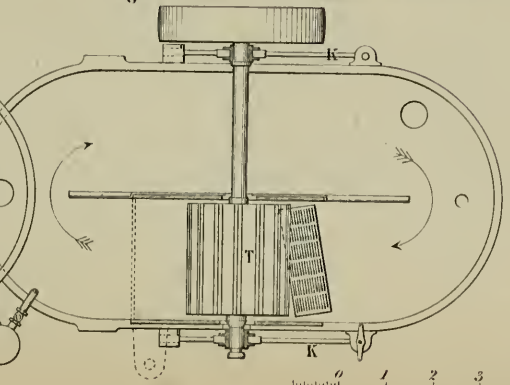
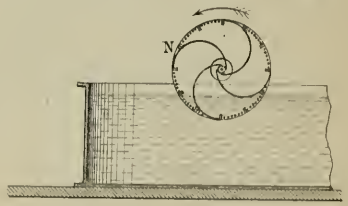


Fig. 14.
Section of Drum Washer.



Scale 1/30th

0 1 2 3 4 5 6 7 8 9 10 Feet.

(*Proceedings Inst. M. E. 1876.*)

Plate 15.

Poacher or Bleaching Tank.

Fig. 15. *Transverse Section.*

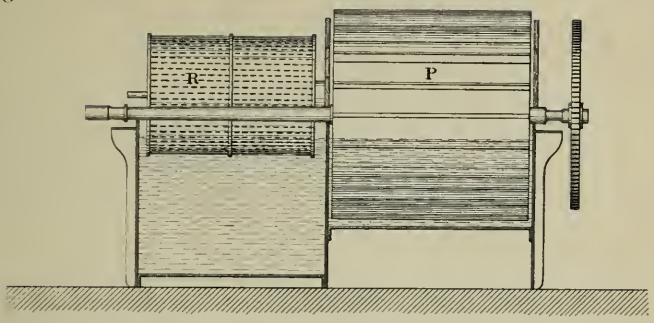


Fig. 16. *Longitudinal Section.*

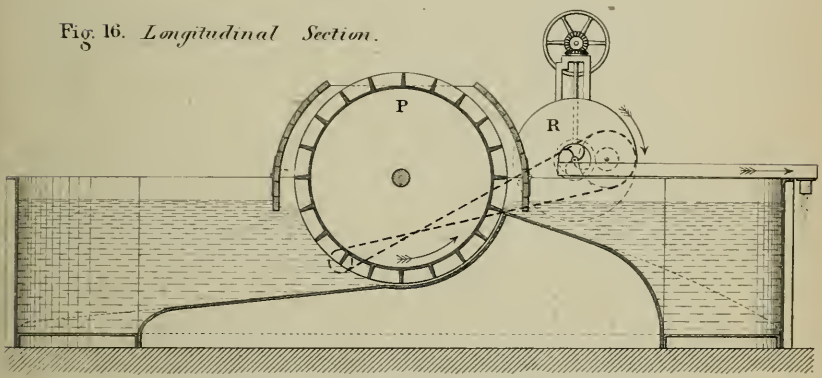
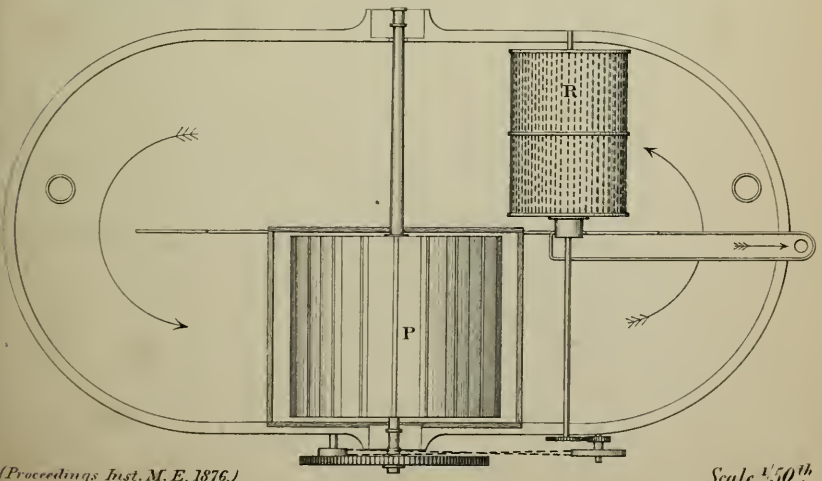


Fig. 17. *Plan.*



(Proceedings Inst. M. E. 1876.)

Scale 1/50th.

PAPER MILL.

Plate 17.

Bleach Mixer.

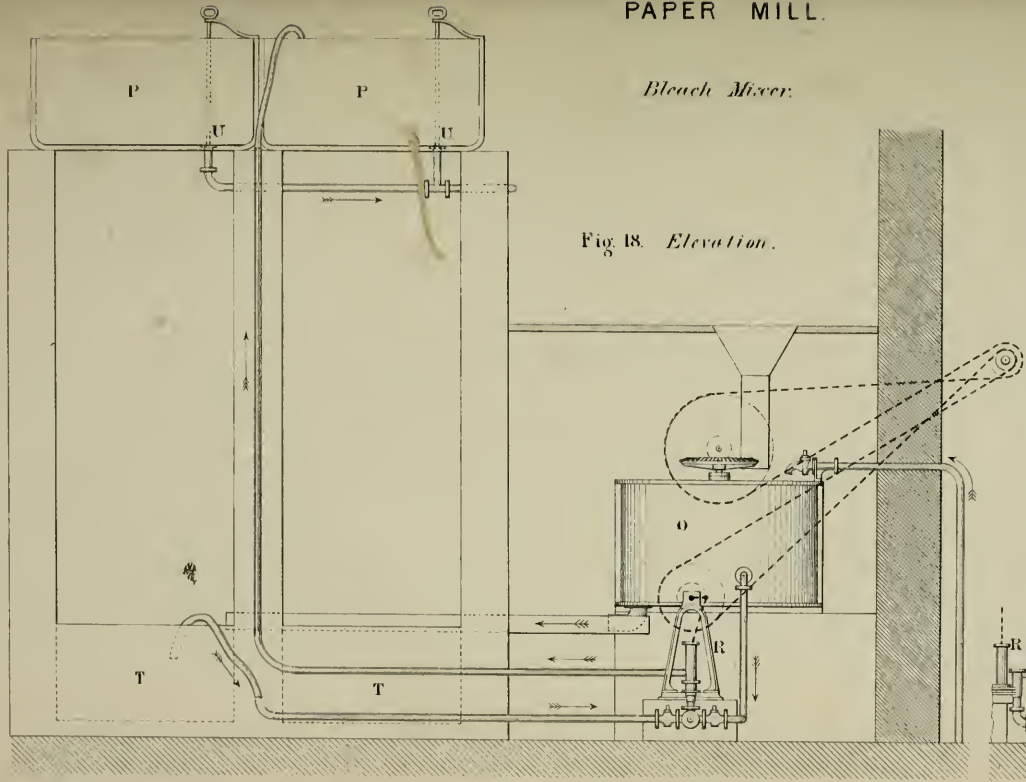


Fig. 18. *Elevation.*

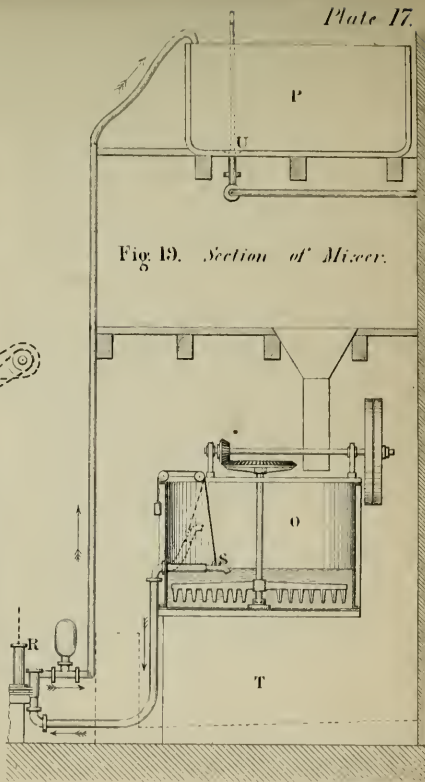


Fig. 19. *Section of Mixer.*

(Proceedings Inst. M. E. 1876.)

Scale 1/70 th

0 5 10 15 20 Feet.

Plate 17.

PAPER MILL.

Paper Making Machine.

Fig. 20. *General Elevation.*

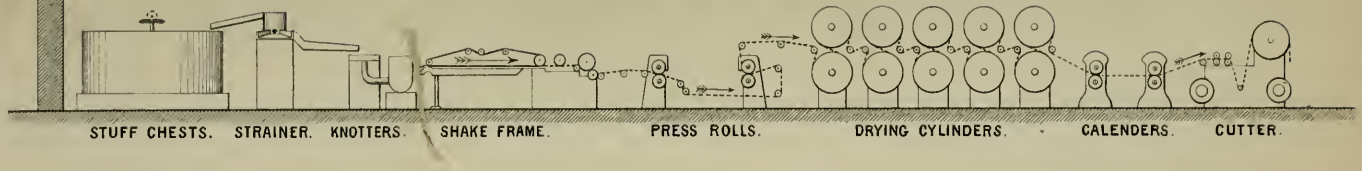
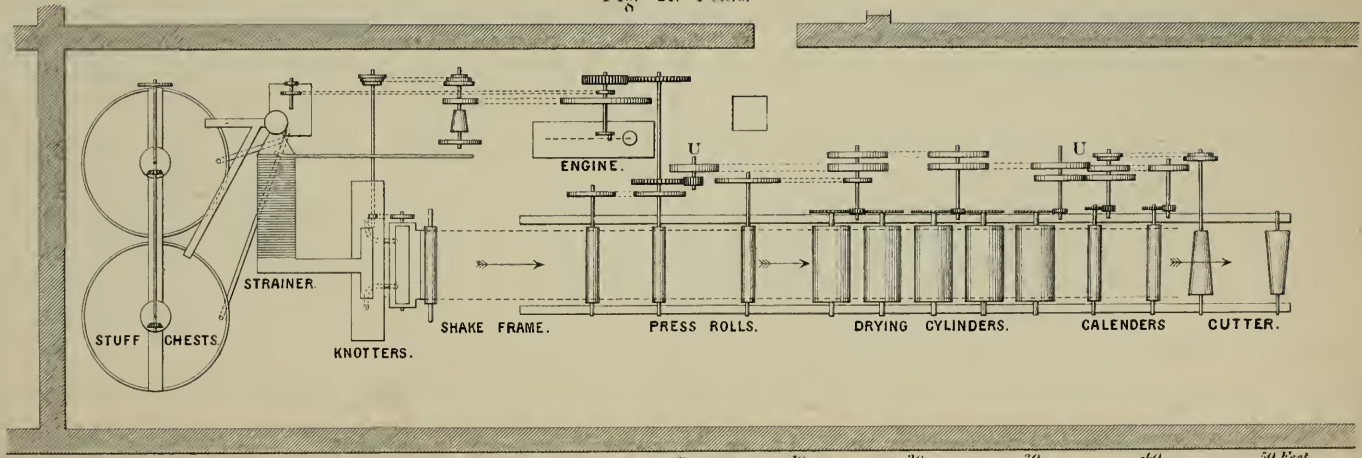


Fig. 21. *Plan.*



(Proceedings Inst. M. E. 1876.)

Scale 1/200th

Plate 18.

PAPER MILL.

Knotters.

Plate 19.

Fig. 22. *Longitudinal Section.*

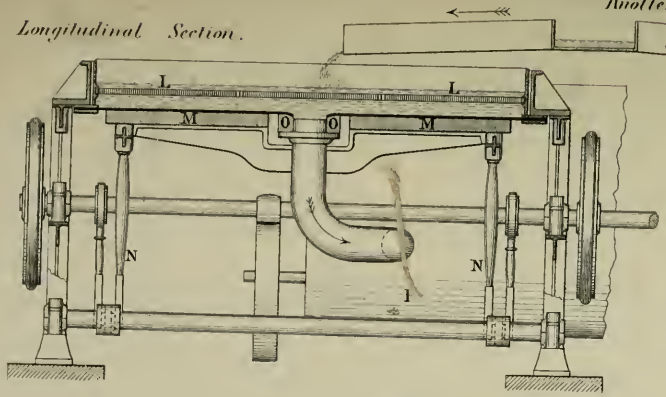


Fig. 23. *Transverse Section.*

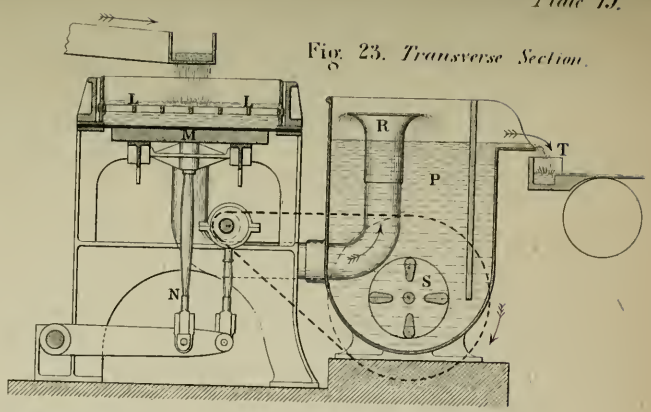
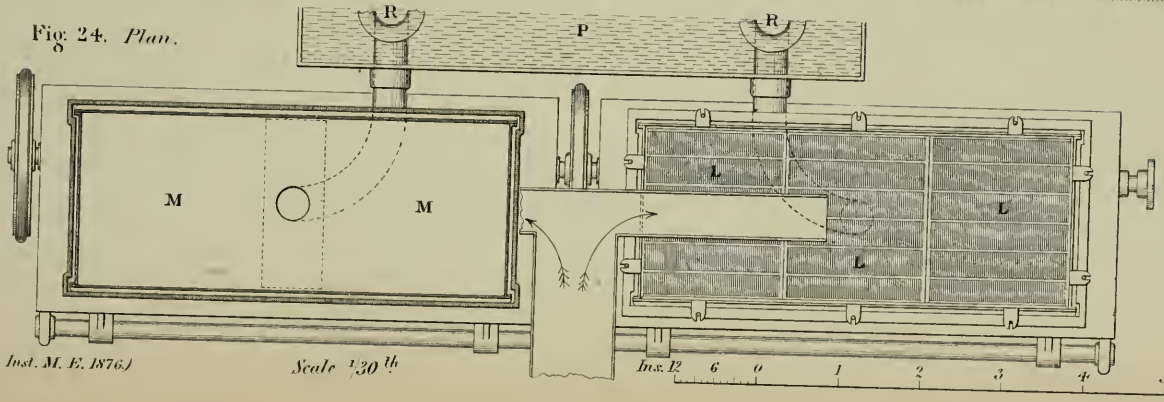


Fig. 24. *Plan.*



(*Proceedings Inst. M. E. 1876.*)

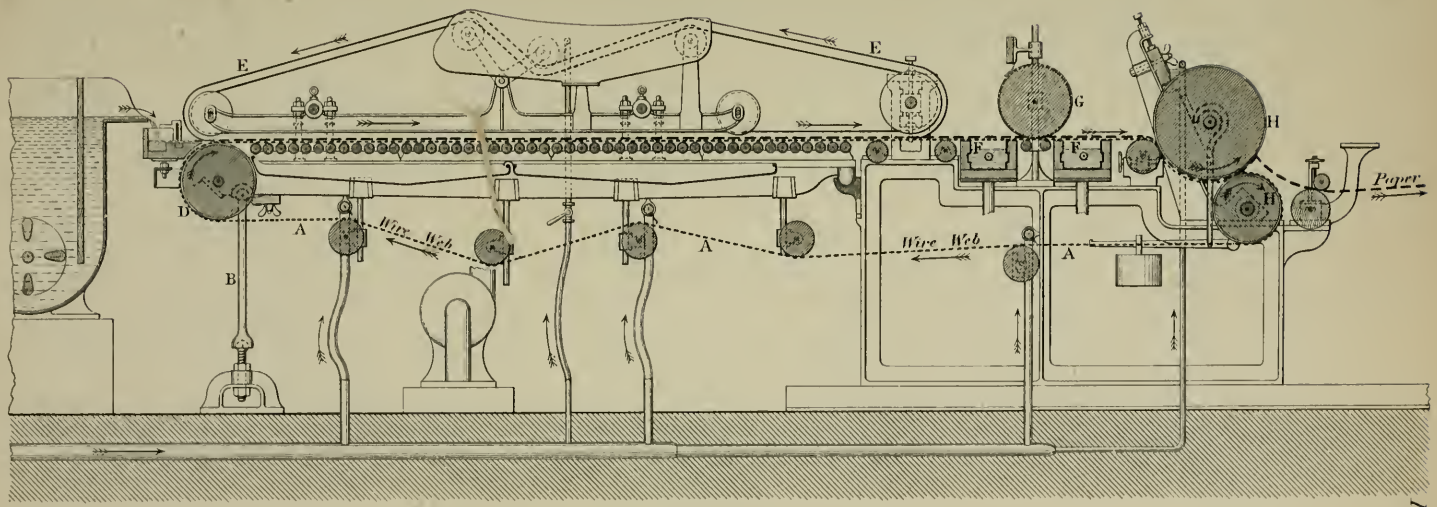
Scale 1/30th

Plate 19.

PAPER MILL.

Shake Frame.

Fig. 25. *Longitudinal Section.*



Scale 1/30th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M.E. 1876.)

Plate 20.

Shake Frame.

Fig. 28. *Elevation of Shake Gear.*

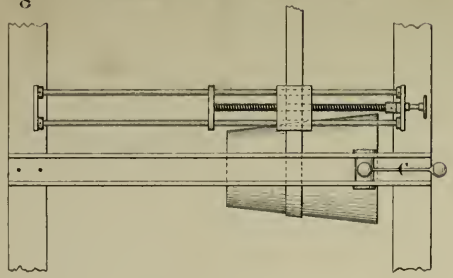


Fig. 26. *Transverse Section at Vacuum Box.*

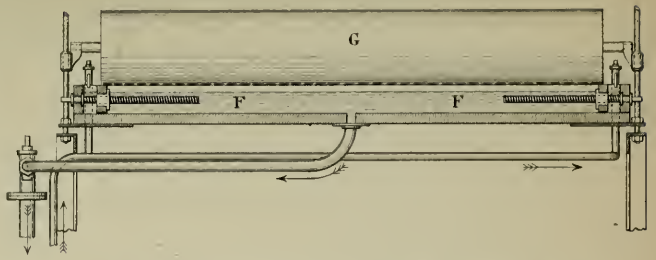


Fig. 29. *Plan of Shake Gear.*

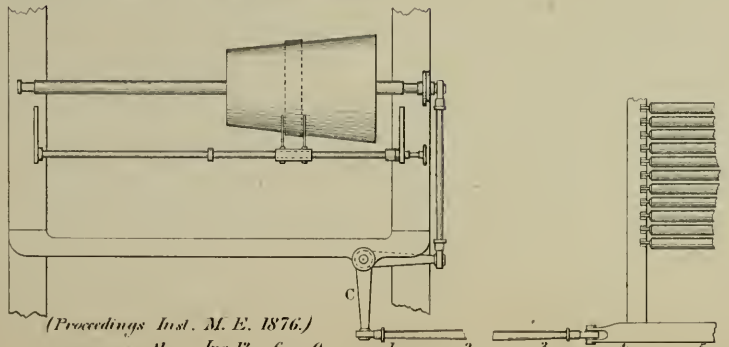
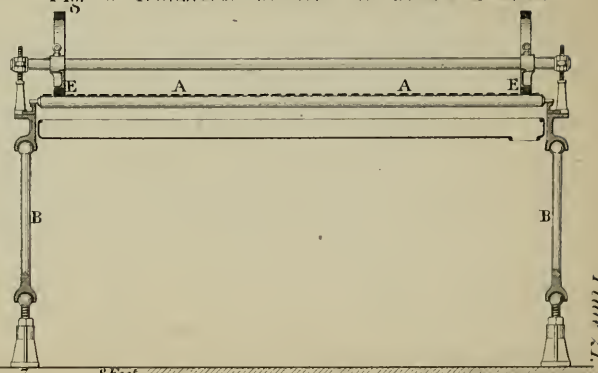


Fig. 27. *Transverse Section at Shake Frame.*



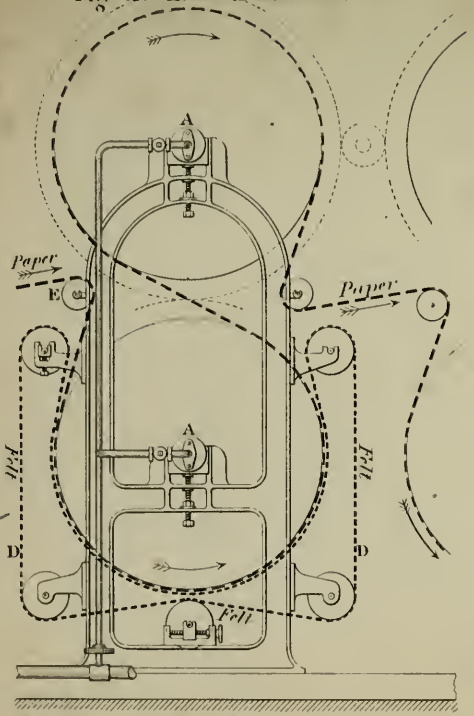
(*Proceedings Inst. M. E. 1876.*)

Scale $\frac{1}{30}^{th}$ Ins. 1 2 6 0 1 2 3 4 5 6 7 8 Feet.

Plate 21.

Drying Cylinders.

Fig. 31. *End Elevation.*



(Proceedings Inst. M. E. 1876.)

Fig. 30. *Transverse Section.*

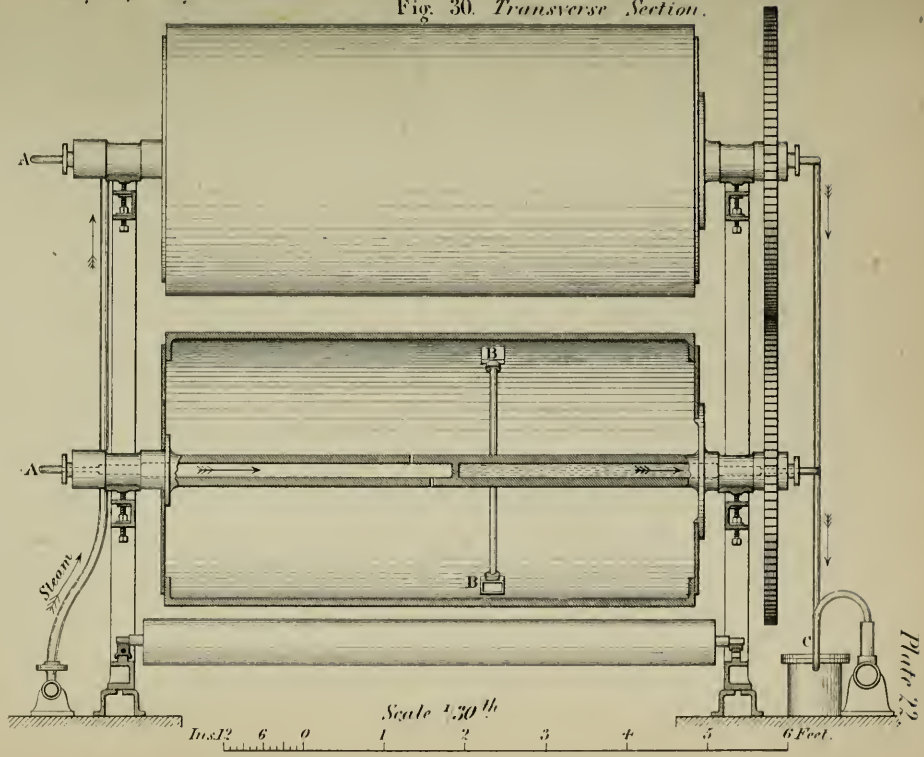


Plate 22.

Paper Cutting Machine.

Fig. 33.

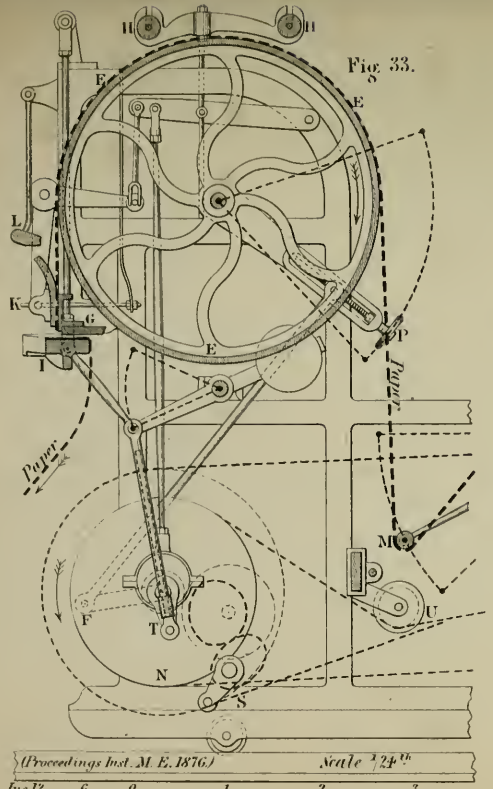
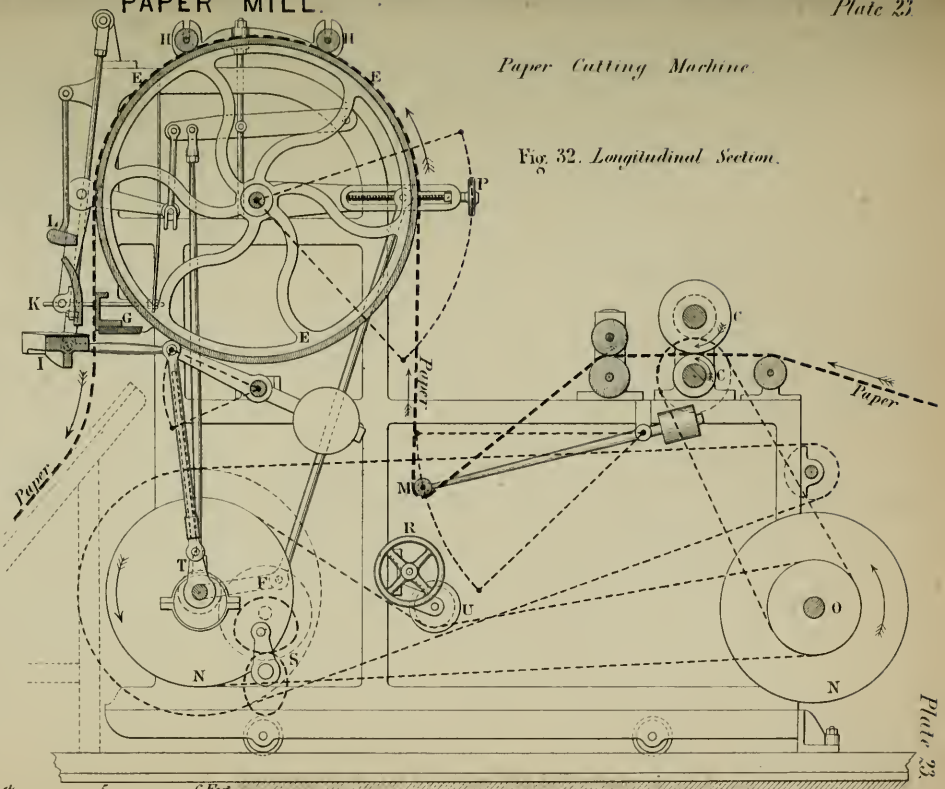


Fig. 32. *Longitudinal Section.*



(Proceedings Inst. M. E. 1876.) Scale 3/24ths

Ins. 1 2 6 0 1 2 3 4 5 6 Feet

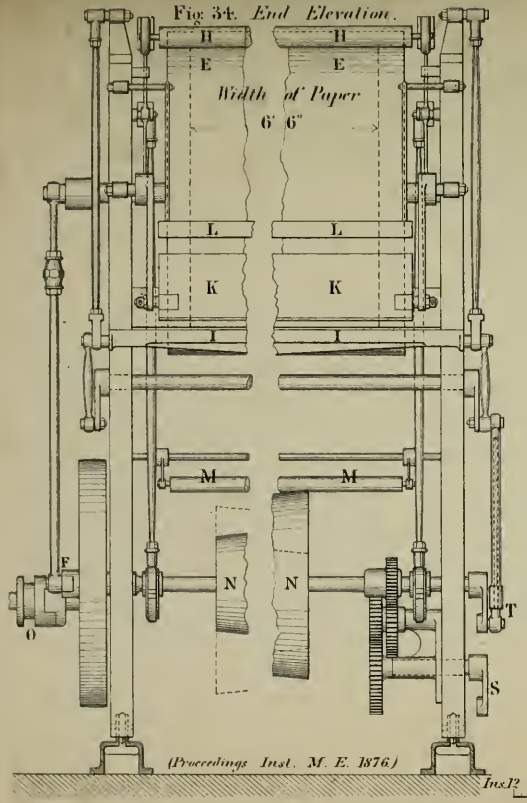
Plate 23.

PAPER MILL.

Paper Cutting Machine.

Plate 24.

Fig. 34. *End Elevation.*



(Proceedings Inst. M. E. 1876.)

Fig. 35. *Plan.*

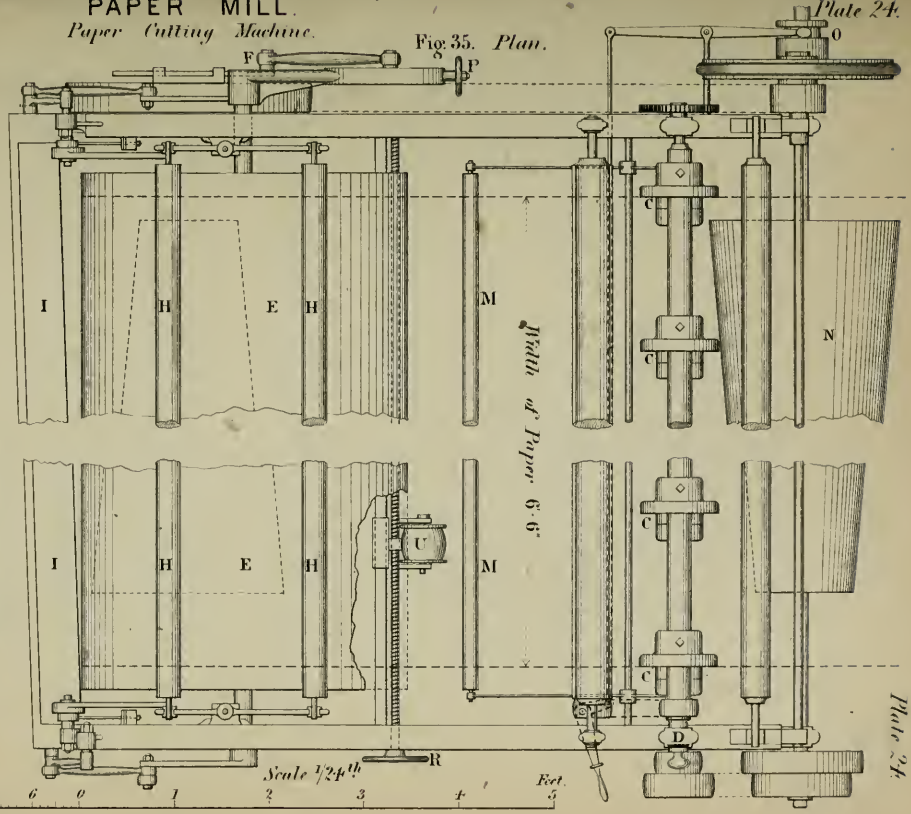


Plate 24.

WATER SUPPLY FROM CHALK.

Fig 1. *Transverse Section of Thames Valley at London*

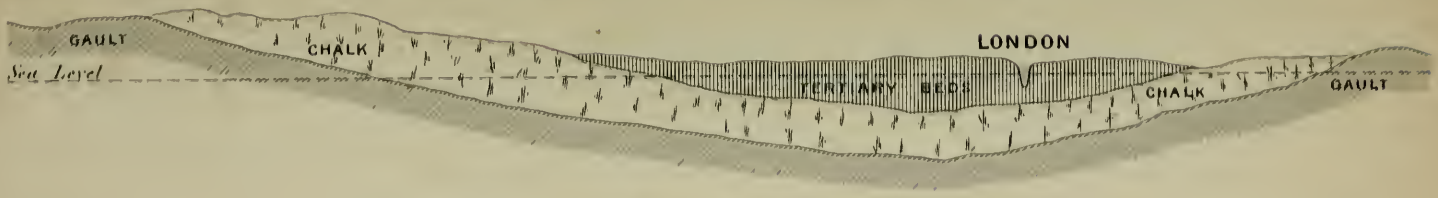
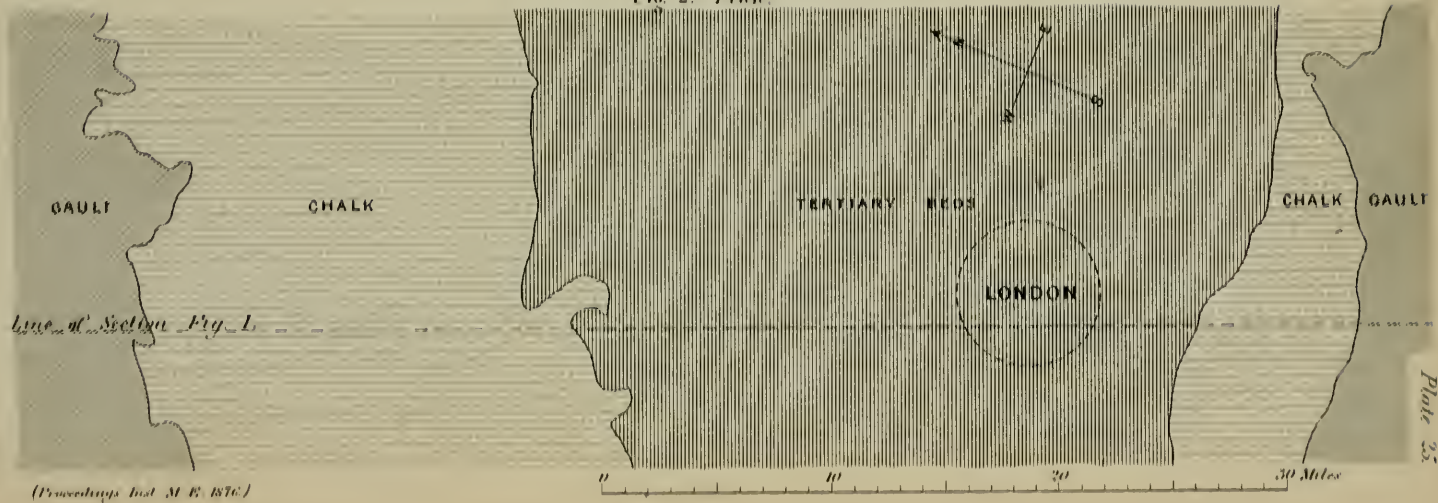


Fig 2. *Plan.*



(Proceedings Inst M E 1876)

Plate 25.

Fig. 3. *Longitudinal Section of Thames Valley from Maidenhead to Purfleet.*

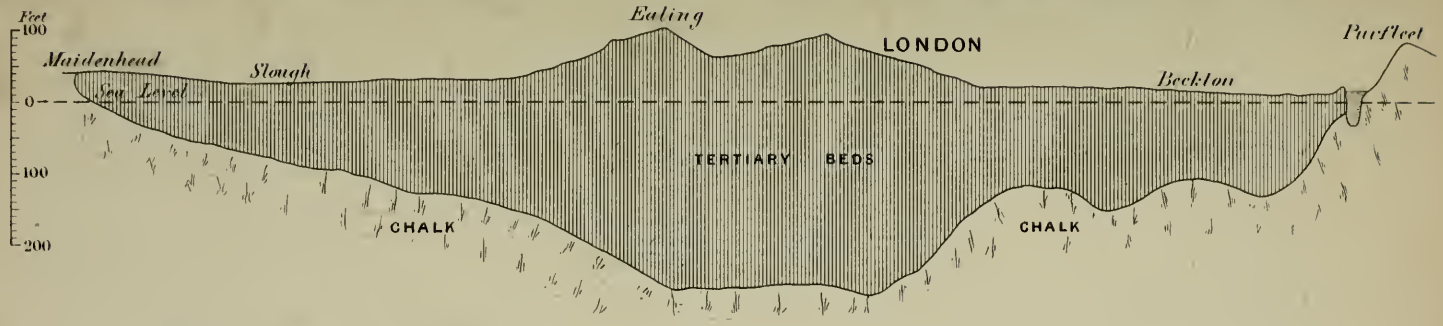


Fig. 4. *Transverse Section from Havering to Crayford.*

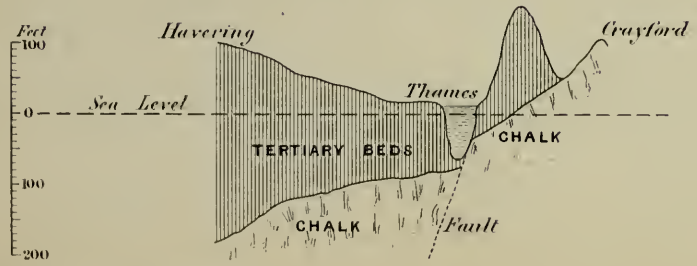
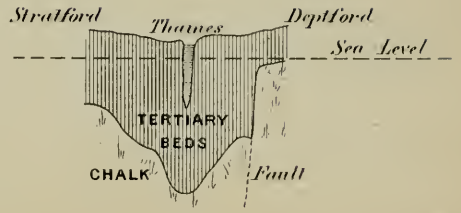


Fig. 5. *Transverse Section from Stratford to Deptford.*

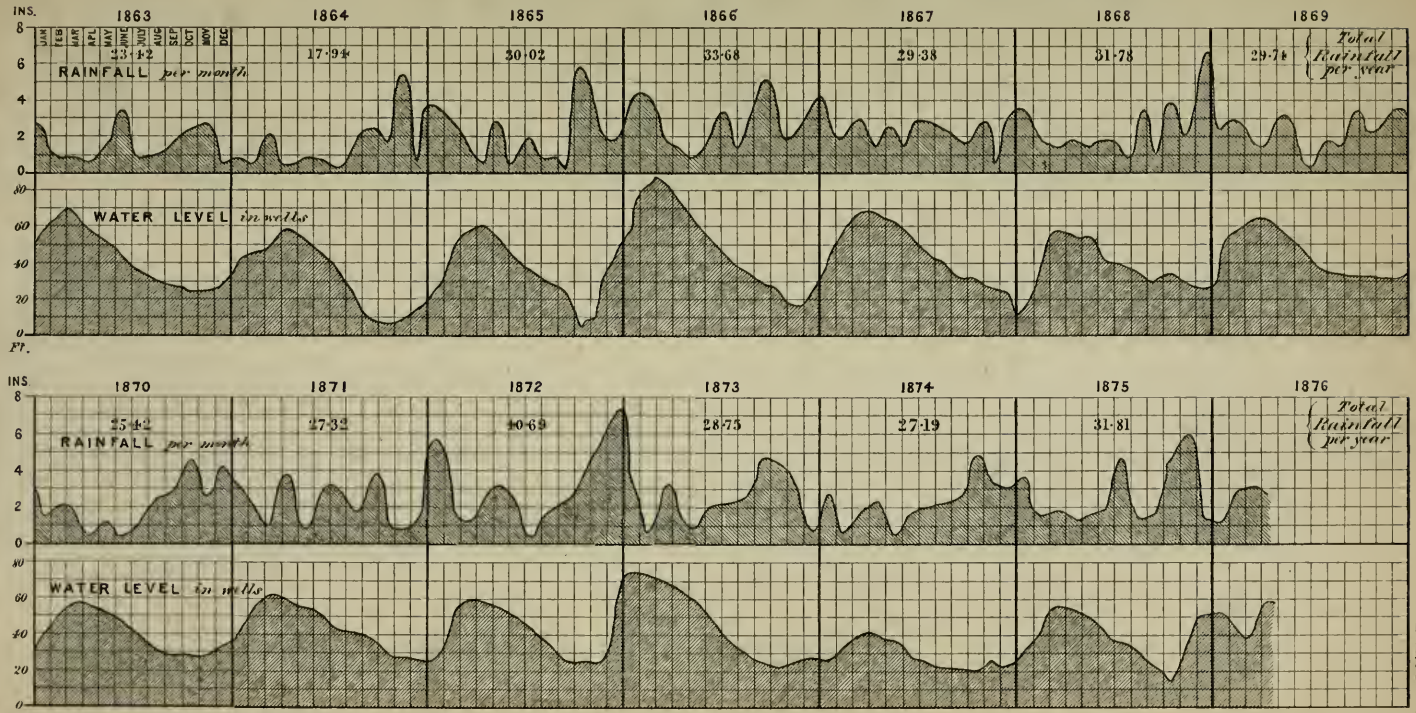


(*Proceedings Inst. M. E. 1876.*)

Plate 26.

WATER SUPPLY FROM CHALK.

Fig: 6. *Diagram of Rainfall and Water Level in Wells at Brighton.*



(*Proceedings Inst. M.E. 1876.*)

Plate 27.

PROCEEDINGS.

May 1876.

The General Meeting of the Members was held at the Institution of Civil Engineers, London, on Wednesday, 3rd May, 1876; Thomas Hawksley, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected :—

MEMBERS.

Henry Adams,	London.
Henry John Card Anderson,	Cairo.
Willoughby Crampton,	Sheffield.
Henry Berriman Cuss,	Tipton.
Samuel Cutler,	London.
John Gillett,	Melksham.
Charles Mattathias Jacobs,	Cardiff.
James Jemson,	Burnley.
Joseph Moore,	San Francisco.
Charles Louis Pinel,	Rouen.
Julius Frederick Moore Pollock,	Leeds.
Thomas Braban Ross,	Chesterfield.
David Scott,	Calcutta.
Arthur Telford Simpson,	London.
Thomas Samuel Speck,	London.
Robert Paulson Spice,	London.
Louis Sterne,	Glasgow.
Henry Hartley West,	Liverpool.
James Wright,	Westbromwich.

The PRESIDENT announced that the Council would at the next Anniversary Meeting submit the question of the removal of the establishment of the Institution to London.

The following paper was then read:—

ON THE LANCASHIRE BOILER, ITS CONSTRUCTION, EQUIPMENT, AND SETTING.

By Mr. LAVINGTON E. FLETCHER, of Manchester.

The Lancashire type of Boiler differs only from the Cornish in one point, namely that the Lancashire boiler has two furnace-tubes whereas the Cornish has but one. In both types of boiler the shell is cylindrical, the ends are flat, and the furnace-tubes are carried through from front to back below the ordinary water line, while the boilers are laid horizontally and fired internally. Internal firing is essential either to a Lancashire or to a Cornish boiler. It is a mistake to speak of an "externally-fired Lancashire" or an "externally-fired Cornish" boiler, though this is frequently done. If the fires are taken out of the furnace-tubes of a Lancashire boiler and put underneath, it is a Lancashire boiler no longer, but becomes an externally-fired double-flued boiler; and if a Cornish boiler be treated in the same way, it becomes an externally-fired single-flued boiler. These boilers owe their names to the counties in which they were first brought into general use. The single-furnace boiler was introduced early in the present century by Trevithick in Cornwall, and is therefore called Cornish. The double-furnace boiler was introduced in 1844 by Fairbairn and Hetherington in Manchester, and is therefore called Lancashire.

In laying down Lancashire boilers, the fact has been too frequently lost sight of that directly a fire is lighted within them they begin to move, the flat ends to breathe outwards, the furnace tubes as well as the shell to hog upwards, and the whole structure to elongate. If sufficient allowance is not made for these movements, straining and sometimes rupture occurs, while the tendency to this is frequently aggravated by putting in an extra

thickness of metal with a view of adding strength, the additional thickness increasing the unequal expansion of the parts. For some years the writer has had opportunities of observing a large number of boilers of the Lancashire as well as other types, in work under the inspection of the Manchester Steam Users' Association; and as the result of these observations he has been led to recommend for the use of its members such a construction of boiler, such an equipment, and such a mode of setting, as that described in this paper. This boiler has been very generally adopted by the members, and found to give satisfactory results. It was thought therefore that a description might be of service to the Institution of Mechanical Engineers. It is not set forth as a work of origination but one of selection and adaptation. The boiler described is safe for a working pressure of from 75 to 100 lb. per sq. in. Its structure is elastic, so that it may not be rent or disturbed by the movement of the parts, resulting from alternate expansion and contraction; and it is so set and the fittings are so arranged that the whole may be above board and accessible to inspection. The writer does not agree with the view, so obstructive to improvement, but too generally held, that anything will do for a boiler, and that it is only a boiler after all. He thinks that a boiler should receive as much attention as an engine; that it should be made with as much accuracy and attended with as much care; that the fireman should not be condemned to work in a dark dirty cellar, called a stoke-hole, and the boiler be assumed to be necessarily black and grimy; but that the boiler should be placed in a suitable house kept bright and cheery, and the fittings as well as the whole structure kept clean and in first-rate working order; also that the fireman should be stimulated to become as proficient in the art of using his shovel and managing the fire as a fitter in using his file and erecting an engine. If this practice, happily adopted by some, were to become general, and first-class boilers were laid down instead of low-priced ones, the scientific boiler-maker would have fairer scope, the steam user would derive economy, and the public would be benefited by the prevention of explosions as well as by the abatement of the smoke nuisance.

The Lancashire boiler has many variations, besides the simple form already described. There is the Galloway boiler, in which the furnaces instead of running through from one end to the other unite in an oval flue strengthened with conical water pipes. There is the Multitubular, in which the furnace-tubes unite in a combustion chamber, from which a number of small flue tubes about 3 in. diameter and 6 ft. long run to the back of the boiler. There is Hill's Multiflued boiler, in which seven flues about 11 in. diameter and 8 to 10 ft. long take the place of the small flue tubes in the multitubular boiler. There are also others in which the furnace-tubes branch off to the sides or the bottom of the shell, instead of running right through to the back end. To all these variations of the Lancashire boiler, and also to the Cornish, this paper applies as regards the construction of the shell and furnace-tubes, as well as in regard to the setting and equipment of the whole.

To assist in the construction of Lancashire boilers for high pressures, the Manchester Steam Users' Association authorised the making of a boiler expressly for undergoing a series of hydraulic bursting tests; and the manufacture of the boiler was entrusted to Mr. Beeley of Hyde Junction, who rendered valuable assistance in the prosecution of the trials. This experimental boiler was 7 ft. diameter, which is the usual size for mill service, and was adapted for a working pressure of 75 lb. per sq. in. Eleven experimental bursting tests have been made, careful observations being taken of the behaviour of the boiler while under pressure. These tests have furnished valuable information, and when they are completed the results will be fully published. Some of the results are given in this paper. In order to preserve the precise form and character of the rents produced, the solid plating around them has been cut out of the boiler intact; several of these specimens are exhibited at the meeting. An actual end plate of a boiler 7 ft. diameter, got up and equipped in accordance with the standard adopted by the Manchester Steam Users' Association, has been prepared for exhibition.

In describing the boiler under consideration, which is shown in Figs. 1 to 3, Plates 5 and 6, it is proposed to treat firstly on its

construction, secondly on its equipment, thirdly on its setting, and then finally to give a few particulars as to weight and cost, heating surface, and working results.

Construction.

Dimensions.—Short boilers are found to do more work in proportion than long ones; this has been confirmed by experiments on the rapidity of evaporation by Mr. Charles Wye Williams and others. Also short boilers strain less than long ones, and are therefore less liable to need repair. A length of 30 ft. should be the maximum, while with regard to the minimum some Lancashire boilers to suit particular positions have been made as short as 21 ft. and found to work well, though the fittings become rather crowded. The length recommended and now generally adopted is 27 ft.

The diameter of the boiler is governed by the size of the furnaces, which should not be less than 2 ft. 9 in. to admit of a suitable thickness of fire and afford convenience in stoking. Thick fires are more economical than thin ones. The space between the two furnace-tubes should not be less than 5 in., and that between the furnace-tubes and the side of the shell 4 in., in order to afford convenient space for cleaning and for the free circulation of the water, as well as to give sufficient width of end plate for enabling it to yield to the expansion and contraction of the furnace-tubes. With this width of water space it will be found that furnace-tubes having a diameter of 2 ft. 9 in. require a shell of 7 ft., which will afford a headway of about 2 ft. 9 in. from the crown of the furnaces to the crown of the shell. A furnace 3 ft. diameter gives room for a thicker fire than one 2 ft. 9 in., but it requires a shell 7 ft. 6 in. diameter. For high pressures, the smaller diameter of 7 ft. is generally preferred, and has come to be adopted as a standard size for mill boilers throughout Lancashire, though one of 7 ft. 6 in. makes a good boiler and gives a greater Ind. H. P. per lineal foot of frontage than one of 7 ft. The diameters both of the shell and of the furnace-tubes are measured internally, that of the shell being taken at the inner ring of plating.

Ends.—The ends, more especially the front, are the seat of the grooving action which occurs in Lancashire boilers when disproportioned. These grooves occur inside the boiler and around the furnace mouth, as shown at R S in Figs. 4 and 5, Plate 7. They are the product of mechanical and chemical action combined. The plate is fretted by being worked backwards and forwards by the movement of the furnace-tubes consequent on the action of the fire, and when in that condition is attacked by the acidity of the water. To prevent this grooving, the ends should be rendered elastic so as to endure the buckling action without fatigue. To secure this elasticity there should be not only a sufficient width of end plate between the two furnace-tubes as well as between them and the shell, as already explained, but also a space of 9 in. between the centre of the bottom rivet in the gussets and those at the furnace mouth. Also five gusset stays are found to work in better than any other number. With five gussets, one falls on the centre line, which is not only the weakest part of the front end plate and thus where it requires the most support, but also where it can be held fast without resisting the movements of the furnace-tubes. The part of the end plate that should be left free is that immediately over the furnace crowns. With four gussets, as shown in Fig. 4, the end plate is more unguarded at the centre, which is the weakest part, and more confined immediately over the furnace-tubes, which is the line of motion.

The thickness of the end plates is sometimes as much as $\frac{3}{4}$ in. for pressures of 60 lb. per sq. in. This thickness however is quite unnecessary, and only tends by its rigidity to cramp the furnace-tubes and strain the parts. Half an inch has been repeatedly and successfully adopted in boilers for pressures of 75 lb. per sq. in., and 9-16ths in. when that pressure has been exceeded. These thicknesses have proved amply sufficient.

In applying the hydraulic test to boilers of the construction and proportions now described, before leaving the maker's yard, it is the practice to carry the pressure up to about 150 lb. per sq. in., and to strain fine cords across the flat ends to act as straight edges from which to gauge the ends, measurements being taken at twelve points

before the test, during the test, and after the test. It is found as a rule that the plate under pressure bulges outwards at the centre from $\frac{1}{16}$ to $\frac{1}{8}$ in., and on the removal of the pressure returns to its original position without suffering any permanent set. In the experimental hydraulic bursting tests, the ends, though only $\frac{1}{2}$ in. thick, have stood repeatedly a pressure of 275 lb. per sq. in. without leakage or any appearance of distress; but on the pressure being raised to 300 lb. the front end plate displayed signs of weakness in the vicinity of the mudhole A beneath the furnace-tubes, Fig. 2. With this exception the greatest bulging was $\frac{1}{8}$ in. at the front, and $\frac{3}{16}$ in. at the back, while the greatest permanent set was only $\frac{1}{16}$ in.

Longitudinal stays are frequently introduced to assist the end plates. In the experimental tests the longitudinal stays were taken out, so that it is clear they are not absolutely necessary where the gussets are substantial. Should it however be thought desirable to adopt them, either as an extra precaution or as afterclaps to assist the gussets when too weak, they will be found easy of introduction. They are therefore shown at B in Figs. 1 and 3, and it will be observed that they are secured at each end with double nuts, one inside the boiler and one outside, and are placed as much as 14 in. above the level of the furnace crowns, and as close together as convenience will allow. When placed directly over the furnace crowns, and only a few inches above them, they confine the furnace-tubes too strictly, and straining ensues. A single stay on the vertical centre line of the front end plate is correct in principle, but two are more convenient in application.

To increase the elasticity of the front end plate, it is attached to the shell by an external angle-iron rather than by an internal one or by flanging. It is not necessary to attach the end plate at the back of the boiler with an external angle-iron, and when this has been done the angle-iron has been found to be injured by the action of the flame.

Both of the end plates, instead of being made in two pieces riveted together at the joint, are welded. This affords a flat surface, which in the case of the front end is more convenient for the

attachment of the mountings. Also both of them are turned in the lathe at the outer edge, so as to be rendered perfectly circular, and are bored out at the openings for the furnace-tubes.

Furnace-Tubes.—The longitudinal joints in the furnace-tubes are welded when the plates are of iron, and double-riveted when of steel, each belt of plating being made in one length and thus having but one longitudinal joint. All the transverse seams of rivets are strengthened with Adamson's flanged joint, or with an encircling hoop either of Bowling iron, T iron, or other approved section. Adamson's flanged seam is shown in cross section in Fig. 6, Plate 8, the T seam in Fig. 7, the Bowling hoop in Fig. 8, and the Bolton steel hoop in Fig. 9. One of the evils that has attended internally-fired boilers has been the frequent collapse of the furnace-tubes; but this danger is completely avoided by strengthening the tubes as just described, whereby, instead of being weaker than the shell as before, they are rendered stronger. This has been shown by the experimental bursting tests, in which, while the shell has been burst repeatedly, the furnace-tubes have not suffered at all, nor shown any movement on being gauged. In some cases Petrie's water pockets, shown in Figs. 12 and 13, Plate 9, and in others Galloway's conical water pipes, shown in Fig. 11, are introduced as a precaution against collapse; while in others again the water pipes are made parallel, as in Fig. 3, and either riveted or welded in place, so as to form one piece with the flue tube. In all cases however the transverse seams of rivets over the fire should be strengthened with flanged seams or encircling hoops; and it is considered desirable to continue this mode of construction throughout the entire length of the boiler, whether water pockets or water pipes are introduced or not.

The thickness of the plates in the furnace-tubes is sometimes as much as $\frac{1}{2}$ in. This leads to violent straining and frequent leakage at the furnace mouths and other transverse seams of rivets. Many furnace-tubes 2 ft. 9 in. diameter, though only $\frac{5}{16}$ in. thick, have stood a hydraulic test of 120 lb. per sq. in. without movement, and have worked satisfactorily for years at a steam pressure of 60 lb. It is advisable however to have them a little thicker than this, in order to

afford a margin for waste through corrosion, and also, when the flanged seam is adopted, in order to allow for the thinning that occurs in drawing the metal to make the flange. A thickness of $\frac{3}{8}$ in. is sufficient for a working pressure of 75 lb. per sq. in., $\frac{13}{32}$ in. for a pressure of 80 lb. or 90 lb., and $\frac{7}{16}$ in. for 100 lb. per sq. in.

Stays are sometimes introduced for supporting the furnace-tubes. Such stays however in the Lancashire boiler are unnecessary, and when rigid are decidedly objectionable. Furnace-tubes should be left free to move. As soon as a fire is lighted within them the top of the tube becomes hotter than the bottom and elongates. This makes the tube arch upwards. In conducting a series of trials in 1867 and 1868 for the South Lancashire and Cheshire Coal Association on the evaporative efficiency of their coals, and also on the comparative merits of different boilers, the writer had three gauge-rods attached to the crown of the furnace-tubes of two Lancashire boilers, and carried up vertically through the external shell by means of brass stuffing-boxes, so that a ready opportunity was afforded of witnessing the rise and fall of the furnace-tubes; while as the gauge-rods divided the tubes into equal lengths, a comparison could be drawn as to the movements of the different parts. Constant observation showed that the distortion of the tubes varied very much at different times, being most severe shortly after lighting the fires, while the colder the water to start with, the greater was the rise of the crown. As soon as the water became generally heated the gauge-rods retired to their old position, and the distortion of the furnace-tubes seldom lasted more than an hour. The boilers were 28 ft. long, the furnace-tubes of steel $\frac{5}{16}$ in. thick in one case, and of iron $\frac{3}{8}$ in. in the other. Care was taken not to strain the boiler by severe firing, steam being got up with the dampers only partially open. Yet the furnace-tubes rose $\frac{3}{8}$ in. when the flames passed around the boiler in the external brickwork flues in the ordinary way, and $\frac{1}{2}$ in. when they passed off direct to the chimney without heating the outer shell. The curve that the flue appears to assume is not a segment of a circle. The gauge-rod at a quarter of the length of the boiler from the front showed in one case as high a rise as the rod placed midway in the length of the boiler, and in another case $\frac{1}{16}$ in. more. This is

just what might be expected from the local action of the fire, and accounts for the grooving action being far more severe at the front end of a boiler than at the back, and shows the importance of affording greater elasticity at that part. Furnace-tubes lashed to the shell often tear themselves away from it in ordinary work, and the fractured stay rubbing against the shell leaves a witness of its movements, the amount of which frequently exceeds that just mentioned. In one case a furnace-tube that had a stay tying it to the top of the shell was found to have crumpled up the stay and broken it by an upward thrust, showing how little need there had been for trying to keep the furnace-tube from drooping.

Shell.—The shell, which is $\frac{7}{16}$ in. thick for a pressure of 75 lb. per sq. in., and $\frac{9}{16}$ in. thick for a pressure of 100 lb., is composed of plates about 3 ft. wide, which are laid in not more than three lengths round the circumference, in order that the longitudinal seams may clear the brickwork seatings. The longitudinal seams are so arranged as to break joint and avoid the centre line along the top and bottom of the boiler. In all the longitudinal rents obtained under the experimental hydraulic tests, the plates bulged outwards at the middle of their width, and this action was observed to a slight extent before rupture, showing that the greatest strain and thus the point of first fracture occurred at or near the centre line of each plate. This would seem to show that breaking joint is of practical advantage, and that a boiler composed of wide plates is not so strong as one composed of narrow ones.

There is no steam dome. Steam domes are expensive, they weaken the shell, and often give trouble from leakage at the base. Added to this they are inconvenient in carriage, as well as in revolving a boiler on its seat, as it is sometimes desirable to do for repairs; they are also inconvenient in covering the boiler over, and in the great majority of cases, if not in every instance, they are for stationary boilers perfectly useless. To prevent priming, an internal perforated pipe C, Figs. 1 and 3, is adopted in place of the dome. Under hydraulic pressure with a steam dome 3 ft. diameter, $\frac{7}{16}$ in. thick, and the whole of the shell plate at its base cut away so

as to form an opening as large as itself, the flange at the base of the dome ripped at a pressure of 150 lb. per sq. in. At a second trial with a dome of the same diameter, and a portion only of the shell plate cut away, the dome strained so much round its base and caused such violent leakage that a pressure of more than 235 lb. could not be obtained. At a third trial, the steam dome having been removed and refixed with stouter rivet heads, so as to resist the upward strain that was induced, the flange at the bottom of the dome ripped on the centre line of the boiler at a pressure of 260 lb. per sq. in. In this instance the workmanship was all good and sound, but where the quality of the plates is inferior or the domes are attached with reedy angle-irons, the weakening effect must be much greater. Steam domes clearly establish a weak point in a shell, and are better avoided.*

The manhole D, Fig. 1, is guarded with a substantial raised mouthpiece of wrought iron, welded into one piece, flanged at the bottom and attached to the boiler with a double row of rivets, the thickness of the upper flange being $\frac{7}{8}$ in., and of the body $\frac{3}{4}$ in. This has been found to stand a test of 300 lb. per sq. in. without the slightest indication of straining. A raised wrought-iron manhole mouthpiece is exhibited. It is too frequently the practice not to strengthen manholes with any mouthpiece at all. Many explosions have arisen from this cause, rents starting in the first place from the unguarded manhole, and then extending all over the boiler. The loss of strength is owing not simply to the amount of metal cut

* A striking illustration of the weakness of steam domes has recently been furnished by two marine boiler explosions, one occurring on 26th June 1875, on board the S.S. "Marcasite," the other on 1st July 1875, on board the S.S. "Renown." In both these cases the steam domes were planted on cylindrical shells, secured thereto by flanging and a double line of rivets. In both cases the dome was blown off, rending all round at the base, the rent running through the inner line of rivet holes for the greater part of its course and through the solid metal at the root of the flanging for the remainder. The diameter of the domes in each case was about 4 ft. and the thickness of the plates $\frac{1}{4}$ in. The dome of the "Renown" blew off at about the ordinary working pressure of 65 lb., and that of the "Marcasite" at somewhat above the ordinary working pressure, but the exact amount is not known.

away by the opening, but also to the action of the cover, which in unguarded manholes is generally internal. This internal cover bears on a narrow edge of plating all round, and is driven outward by the pressure of the steam, and also pulled in the same direction by the bolts in tightening the joint. In fact the cover acts as a sort of mandrel, which being forcibly driven through the manhole splits the boiler open. A heavy hydraulic test shows this action of the cover, by curling the boiler plate up around the manhole. Added to this, the joint is apt to leak, and thus to induce corrosion and thin the plate, which not only reduces its strength but leads to extra force being applied to tighten the joint; several explosions have occurred shortly after the joint has been re-made. It has been the general practice till recently to make raised mouthpieces of cast iron. This however is not wise for the high pressures now in use. A raised manhole mouthpiece having a clear opening of 16 in. diameter, which is the usual size, involves a hole in the shell plate at its base of about 20 in. diameter. The plate in which this hole is cut, unless it be duly strengthened, becomes the weakest part of the boiler when the longitudinal seams are double-riveted, the furnace-tubes suitably strengthened with encircling rings, and the ends well stayed; so that the stability of the entire structure depends on the mouthpiece: if that fails, the whole structure fails. Under these circumstances it is evidently unwise to risk the safety of the boiler on a piece of cast iron. This view is confirmed by the behaviour of cast-iron manhole mouthpieces under hydraulic pressure. Several have failed under the ordinary test at the boiler-maker's yard, while at one of the experimental bursting tests a cast-iron manhole mouthpiece of substantial pattern, measuring $1\frac{7}{8}$ in. thick in the lower flange and 1 in. in the body, rent at a pressure of 200 lb. per sq. in., though the metal exhibited a good sound fracture. This specimen is exhibited to the meeting. It would appear that under pressure there is a considerable upward strain on the plates around the mouthpiece; and that while wrought-iron mouthpieces are able to accommodate themselves to this without distress, cast-iron ones are not. These tests have shown that wrought-iron manhole mouthpieces are much superior to cast-iron,

and that the sooner cast-iron ones are generally superseded by wrought-iron the better.

The mudhole A, Figs. 1 and 2, at the front of the boiler, beneath the furnace-tubes, is also fitted with a substantial mouthpiece. This in some cases is external, like the manhole mouthpiece, and in others internal, as shown in Fig. 1. The internal ones have the advantage of being less in the way. In either case the surfaces at the joint between the body of the mouthpiece and the cover are faced true, so that the parts may be brought together metal to metal.

The safety-valves E and F and the steam stop-valve G are fixed to the shell, each with its own independent opening, and not grouped upon the manhole mouthpiece as is sometimes the case, the object of grouping them being to reduce the number of holes, on the principle that the fewer holes made in a boiler the better. This argument is plausible but fallacious. The manhole makes the largest opening, and therefore exerts the greatest weakening effect. The weakest link in a chain is the measure of the strength of the whole; so that fixing the steam stop-valve and safety-valves directly to a boiler with suitable fitting blocks does not weaken it. Moreover, for convenience in attaching the fittings, these group manhole mouthpieces are made of cast iron, which as already explained is objectionable. It is therefore recommended that manhole mouthpieces should not be complicated by the addition of the safety-valves or other fittings, but that each should be fixed direct to the shell and have its own independent attachment and thoroughfare.

Blocks for the attachment of Fittings.—In old-fashioned practice the fittings were bolted directly to the cylindrical portion of the shell. This led to the wasting of the shell through leakage at the joints; so that it has long since been the practice to rivet short stand-pipes to the cylindrical portion of the shell and bolt the fittings thereto, the joint surface between the flanges being planed up true. These stand-pipes, frequently termed "fitting blocks," are not only more convenient for the attachment of the fittings, but also, being riveted to the plate and made of substantial section, strengthen the plate round the hole cut in the shell.

They are as a rule made of cast iron, but it becomes a question whether, with the high pressures now in use, they should not be made of wrought iron. At one of the experimental bursting tests, a fitting block for a 6 in. steam valvebox was found to give way before any other part of the boiler, at a pressure of 275 lb. per sq. in., though the flange was $1\frac{5}{8}$ in. thick, the body $\frac{7}{8}$ in., and the metal sound.

Seams of Rivets.—Those running longitudinally in the cylindrical shell are all double-riveted, with $\frac{3}{4}$ in. rivets pitched about $2\frac{1}{2}$ in. longitudinally and 2 in. diagonally. The remaining seams throughout the boiler are single-riveted only, the rivets being 2 in. pitch. To double-rivet the transverse seams adds but little, if any, strength to the boiler, though it increases its weight and cost. It would appear that the strain upon the transverse seams of rivets in a Lancashire boiler is over-estimated. In a plain cylindrical boiler, without furnace-tubes, the strain on the transverse seams of rivets is precisely half that on the longitudinal seams. By the introduction of the furnace-tubes not only is the longitudinal strength increased, but at the same time the area of the ends upon which the steam acts is lessened, and thus the strain is lessened also; so that in the Lancashire boiler the strain on the transverse seams of rivets is less than half that on the longitudinal seams. The force of this reasoning however is sometimes disputed, and tie rods are introduced to support the transverse seams of rivets in the shell. But in the hydraulic bursting tests, with the tie rods removed, the longitudinal seams of rivets were found to fail in every case before the transverse seams, which never showed the slightest signs of distress and scarcely leaked a drop, while some of the longitudinal seams under severe pressure shortly before rupture leaked profusely.

The riveting is done by machine in preference to hand in the cylindrical shell, in the furnace-tubes, and as far as practicable in the flat ends. In the experimental bursting tests, the machine work in every case proved much tighter than the hand work. The rivet holes in the angle irons, T irons, and flanged seams are drilled, those in the plates being punched by most makers; though by some

the holes are drilled throughout, and the practice of drilling is strongly advocated by them. In investigating an explosion that occurred at Blackburn in March 1874, the mean tensile strength in twelve tests of a solid plate was found to be 21·19 tons per sq. in., and in four tests of a punched plate 20·17 tons, showing a loss by punching of 1·02 tons per sq. in., or about 5 per cent. The question of drilling versus punching, and also of the pitch and diameter of rivets, is one that deserves further consideration; and it may be added that a boiler 7 ft. diameter, and made of plates $\frac{7}{16}$ in. thick, having the longitudinal seams double-riveted with $\frac{3}{4}$ in. rivets, pitched 3 in. longitudinally, instead of $2\frac{1}{2}$ in. as usual, was found tight at a hydraulic pressure of 120 lb. per sq. in. The edges of the plates at the longitudinal seams of rivets are planed and caulked lightly, inside as well as out; though in many cases caulking is superseded by fullering.

Material.—As a rule, boilers made under the inspection of the Manchester Steam Users' Association are of iron in the shell, while steel plates are very frequently introduced in the furnace-tubes for a length of 9 ft. over the fire, and sometimes from one end of the boiler to the other. For the furnace-tubes steel plates have been found to give great satisfaction, but a little suspicion has been entertained with regard to their use for shells, seeing that the plates are then in tension, and that a small flaw through brittleness might extend till it produced serious consequences. "Best best" plates from first-class makers are always recommended, more importance being attached to their ductility than to their tensile strength. Brands however are uncertain, and it is thought desirable that a complete system of testing should be adopted, and that, before a boiler is made, one plate out of the set proposed to be used should be tested as a check, the investigation having special reference to ductility. Low Moor rivets are frequently used and may be recommended.

EQUIPMENT.

Arrangement of Fittings.—The fittings are so arranged that all those requiring frequent access are immediately within reach of the attendant when standing in front of the boiler. The feed is introduced on one side of the front end plate, about 4 in. above the level of the furnace crowns, an internal dispersing pipe H, Figs. 1 and 3, being carried along inside the boiler for a length of about 12 ft., and perforated for the last 4 ft. of its length. On the opposite side of the front end plate is fixed the scum tap, to which is connected a series of sediment-catching troughs K, Fig. 3, fixed inside the boiler. In the centre of the end plate are two glass water-gauges J J, Fig. 2, so that one may act as a check upon the other, a pointer being fixed to show the correct height at which the water should be kept. Immediately above the water-gauges is a dial pressure-gauge L, and above that a dead-weight safety-valve E. Thus whenever the attendant opens the furnace doors to charge the fires, he has the height of the water and the pressure of the steam directly before him. Under his feet is the blow-out tap, and behind him the coal supply, so that everything is ready to hand. He has not to climb a ladder in order to reach the water-gauges or ascertain the steam pressure, nor to mount on the top of the boiler in order to regulate the feed supply. A handle for regulating the dampers is frequently brought to the boiler front. On the top of the boiler are two safety-valves, one a dead-weight valve E of external pendulous construction, the other a low-water valve F, Fig. 1.

But convenience in manipulation is not the only reason for this arrangement of fittings. If the feed be cold and be introduced near the bottom of the boiler, it is apt to induce local contraction, and thereby strain the transverse seams of rivets at the bottom of the shell; but when introduced near the surface of the water and passed through an internal perforated pipe, it becomes dispersed before falling to the bottom. Further, although non-return valves may be introduced, they will sometimes fail and allow the water to escape, whereby the furnace crowns become bare and overheated. When the feed inlet is placed above the level of the furnace crowns, it

will be seen that they cannot be drained bare by leakage at the non-return valve; but when placed at the bottom of the boiler, the boiler may then be emptied by such an occurrence.

Safety-Valves.—The dead-weight valve, which is of the Cowburn type, as shown in Fig. 10, Plate 8, is extremely simple and efficient. The centre of gravity of the load being below the seating renders unnecessary either wing or fang for keeping the valve in position, and it has therefore no frictional surface to get tight or stick fast. These valves are loaded with flat annular plates or rings, and the shell is cast with mouldings around it at the bottom which present the same appearance, the whole being so adjusted that each moulding as well as each annular plate represents a pressure of 5 lb. per sq. in. on the valve. Large numbers of these valves are in use, and they are highly approved. The diameter generally adopted is 4 in., which requires approximately a load of 8 cwt. for a blowing-off pressure of 75 lb., and 11 cwt. for 100 lb. per sq. in. On this valve the addition of two or three bricks produces no appreciable effect, whereas at the end of a long lever the result would be different. To double the blowing-off pressure it would be necessary to add about 8 cwt. to the load for 75 lb., and 11 cwt. for 100 lb. Such an addition there would be great difficulty in attaching to the valve, and if it were done it would be so conspicuous as at once to call attention to the fact. The great weight required to load this valve is considered therefore to be a safeguard: and several explosions due to overloading have been met with, which would have been prevented by its use.

The low-water safety-valve shown at F in Fig. 1 is of the Hopkinson type; but there are also the Kay and the Lloyd low-water valves, which though varying in detail are similar in their object. Each has a lever inside the boiler, to which is attached a float, so that when the water falls below the desired level the float falls also, and thus raises the valve and allows the steam to blow off, thereby not only giving an alarm but also lowering the pressure. Hopkinson's valve is a compound one, having one valve seated on another; the central portion is loaded by a dead weight inside the boiler, and operated

upon by the lever in the event of low water, while the annular portion is loaded by an external lever and weight, and lifts along with the central portion in the event of high steam; these valves therefore blow off on the occurrence either of high steam or of low water. The outer valve is 5 in. diameter, and the inner one $2\frac{1}{2}$ in. The freedom of the steam valve can be tested by placing the hand on the lever when steam is up; while the freedom of the low-water apparatus can be tested by opening the blow-out tap and lowering the water-level to within about 6 in. of the furnace crowns. To overload this valve without increasing the weight outside would necessitate getting inside the boiler and wedging down the dead weight. Under such circumstances the application of the hand to the external lever when steam was up would at once show that something was wrong; and even if this were not detected the external dead-weight valve at the front of the boiler, if free, would come to the rescue, while, if overloaded, this would be apparent at a glance. It is sometimes recommended to have safety-valves under lock and key, but it is preferred by the writer to have them thoroughly open, so that their publicity may be their protection. While it is fully admitted that no arrangement of safety-valves can be contrived which cannot be tampered with by skilled malice, it is thought that the combination of the two valves just described and shown in Fig. 1 forms a very safe arrangement.

Furnace Mountings.—The furnace mouthpieces N N, Fig. 2, are of wrought iron, finished off with a neat brass beading, and kept within the circle of the rivets, so as leave these exposed to view. The firedoors are fitted with a sliding ventilating grid on the outside and a perforated box baffleplate on the inside, the aggregate area of the air passages being about 50 sq. in. for each door, or about 3 sq. in. per sq. ft. of firegrate. The firegrate is 6 ft. long, with the bars in three equal lengths, about $\frac{3}{4}$ in. thick, and spaced $\frac{3}{8}$ in. apart for windage. The bearers consist of two wrought-iron bars carried on wrought-iron brackets riveted to the sides of the furnace-tubes. The standard length of grate is 6 ft., but a shorter one is productive of economy, though the concentration of the fire is more trying to

the boiler, and has been found, where the feed water has not been good, to injure the furnace plates, and render lengthening the grate necessary.

SETTING.

External Brickwork, Flues, and Course of Draught.—The boiler is set on side walls, and rests on firebrick seating blocks presenting a bearing surface 5 in. wide, as shown in Fig. 3, Plate 6. The side flues are 6 in. wide at the top, carried up to the level of the furnace crowns or a few inches above, and down to the level of the bottom of the shell. The bottom flue has a width equal to the radius of the boiler, and a depth of about 2 ft. These dimensions admit of ample room for inspection. By keeping the width of the bottom flue equal to the radius of the boiler, the angle that the bearing surface of the seating block makes with the horizon is 30° for any diameter of shell.

The flame immediately after leaving the furnace-tubes passes under the bottom of the boiler, and returns to the chimney along the side flues. This is not the course approved by Mr. Pole in his treatise on the Cornish Pumping Engine, published in "Tredgold on the Steam Engine" in 1844, in which the setting of the Cornish boiler is spoken of as follows:—"The heated current first impinges on the top of the tube, over which the highest and therefore the hottest portion of the water is lying; it then passes along the side flues, where it finds the surfaces cooler than before; and last of all it traverses under the bottom of the boiler, where the coldest water will always be. By this means the fire current, as it gradually cools, is likewise gradually brought to act upon cooler water, and thereby the best opportunity is afforded for the extraction of the free caloric it contains. . . . . The descending motion of the fire current, as it cools in the flues of the Cornish boiler, is upon statical principles much more natural and more calculated to prevent the unnecessary discharge of heat into the chimney than the ascending principle of the ordinary boilers." Allowing the last heat however to travel under the bottom of the shell does not promote the circulation of the water, or at all events but slowly; so that in

getting up steam the top of the boiler becomes hotter than the bottom, from which straining ensues. If in addition to this, the feed water when cold be pumped in at or near the bottom of the boiler, the straining at the transverse seams of rivets is intensified. Possibly the Lancashire boiler is more subject to straining and seam-rending at the bottom of the shell than the Cornish, as there is a greater body of dead water lying there in the Lancashire boiler, in addition to which the rate of combustion per sq. ft. of firegrate is much more rapid in the Lancashire district than that generally adopted in Cornwall. In consequence of seam rents occurring at the bottom of Lancashire boilers when the last heat is carried underneath, the plan of passing the flame under the bottom immediately on leaving the furnace tubes, and also of introducing the feed water near the surface, has become the general practice. The question of economy is met by the use of feed-water heaters, consisting of a number of water pipes placed in the main flue between the boiler and the chimney, and kept free from soot by an automatic scraper. A good feed heater will raise the temperature of the water to about 240°. This answers two good purposes: it economises the waste heat escaping to the chimney and thus reduces the coal consumption, while at the same time it prevents local cooling, thereby preventing straining and saving repairs. It has been found by experiment that passing the flames from the furnace tubes around the outer shell, instead of direct to the chimney, adds but little to the yield of steam, though it promotes economy of fuel: at the same time it keeps the boiler at a more equable temperature throughout.

The flooring or hearth plates at the front of the boiler are set so as not to butt against the boiler, which is too often the case, but so as to be entirely below it, as in Fig. 2, thus leaving the whole of the front end plate open to view. Where there is a range of boilers, these flooring plates extend throughout the width of the boiler house; and being finished off with a fender-flange where abutting against the boundary walls of the building, as well as against the face of the brickwork setting, they present a very neat appearance. These plates are carried on a complete system of framing, and are arranged for easy lifting. The hearth pit beneath them is open

from one side of the boiler house to the other, and in this is laid the main feed-pipe, as well as the discharge pipe from the blow-out and scum. This pit is about 3 ft. wide by $2\frac{1}{2}$ ft. deep, so as to afford room for access; the flue doors open into it. The face of the brickwork at the front of the boilers is set back 6 in., so as to leave the angle-iron with its circle of rivets perfectly open. The front cross wall beneath the boiler is recessed around the blow-out elbow-pipe, so that it may be free to move should settlement of the boiler take place.

Boiler Covering.—The boiler is covered with an arch of brickwork, leaving a space of about 2 in. between it and the plates, as in Fig. 3; and a layer of cork shavings or a coating of good boiler-composition or other suitable non-conducting substance is introduced into this space. Openings finished off with bull-nosed bricks are worked round the fittings, so as to leave the ring of rivets by which they are attached to the shell exposed to view. Sometimes the boiler is covered simply with a layer of composition, which should not be carried over the flanges of the fittings, as is too often the case, but should be stopped off by means of kerb hoops dropped around the flanges, and a kerb cast-iron nosing to guard the front angle-iron.

Connections.—All connections to boilers should be elastic, so as to allow of their movement. If the main steam-pipe be carried across the boilers and bolted direct to the steam junction-valve, the joints are strained by the rising and falling of the boilers as they are set to work or laid off. To prevent this, a springing length should be introduced between the steam stop-valve G and the main steam-pipe, as shown in Fig. 1. Where the main steam-pipe has a considerable length to travel to the engine, it should not be taken in a direct line, but should either be carried round the boiler house or be led in a horse-shoe shaped course, to give elasticity; this is better than introducing an expansion joint, which is not reliable. Sometimes expansion diaphragms are adopted; but these when as much as 4 ft. diameter have been known to lead to the fractures they were intended to prevent, the internal pressure causing them to bulge outwards, when

it was expected that they would allow the pipes to expand and thrust them inwards. A case of this sort has recently come under the writer's knowledge, in which the main junction-valve was broken off by the thrust occasioned by the bulging of the expansion diaphragm. It is equally important that the feed connection should be elastic; and from the want of elasticity, feed valve-boxes have been known to fracture. For this purpose a copper elbow connecting-pipe P, Figs. 1 and 2, is introduced between the main feed-pipe and the stand-pipe; in some cases a wrought-iron horse-shoe shaped pipe has been adopted instead, with very satisfactory results.

Connections between the steam stop-valve and main steam-pipe are frequently made to incline upwards, as in Fig. 14, Plate 10, so that the water may drain back to the boilers. This plan however is objectionable; for when one of the boilers in a range is laid off, the connecting length becomes filled with water from condensation of the steam, which, cooling by radiation, sets up a violent conflict with the steam, whereby the pipes are sometimes fractured. The action may be illustrated by the commotion which occurs within a locomotive tender when the steam from the boiler is turned into it. Further than this, on opening the steam stop-valve of a boiler that has been laid off, the water lying on the top of the valve, as in Fig. 14, is apt to be carried forward by the rush of steam, like a water hammer and sometimes to burst the pipes. To prevent this the steam-pipe should drain towards the engine, and not towards the boiler, its course being intercepted by a separator fixed as near the engine as convenient. The principle on which these separators act is that of making the steam take a sharp turn, so as to shoot off the water mixed with it into a catch-chamber prepared for the purpose. Many of these separators are now at work; the principle was advocated by Dr. Haycraft of Greenwich, five-and-twenty years ago.

Additional Particulars.

Weight and Cost.—The weight of such a boiler as has now been described, when 7 ft. diameter, 27 ft. long, and made of plates $\frac{7}{16}$ in. thick, is about 12 tons without fittings; with fittings $15\frac{1}{2}$ tons.

The cost at the present time, delivered on the premises of the purchaser within a few miles of Manchester, and including the attachment of the fittings, is about £425. The plan of buying a boiler at so much per ton, and then the fittings at so much extra, is quite given up in favour of purchasing the whole for one sum.

Heating Surface.—Such a boiler has a heating surface in the external shell of 370 sq. ft.; in the furnace-tubes, without water pipes, 450 sq. ft.; in the water pipes 30 sq. ft.: making a total of 850 sq. ft. The firegrate has an area of 33 sq. ft.; this gives for every square foot of firegrate 26 sq. ft. of heating surface.

In feed-water heaters the surface varies; sixty pipes, each affording a heating surface of about 10 sq. ft., are now frequently introduced per boiler, making a total heating surface of 600 sq. ft., or about three fourths of that in the boiler.

Working Results.—From 15 to 20 tons of coal in a week of 60 working hours, or from 17 lb. to 23 lb. per sq. ft. of firegrate per hour may be burnt in such a boiler without distressing it. This may be done without making smoke; all that is needed is to maintain a good thickness of fire, throw on the coal little and often, admit a little air above the bars for a short time after firing, and avoid the use of the rake. The coal may either be spread over the whole surface of the fire or thrown at alternate firings first to one side of the furnace and then to the other, on the "side firing" system introduced by Mr. C. Wye Williams.

A Lancashire boiler experimented on at Wigan, with furnaces 2 ft. 7½ in. diameter and a firegrate 4 ft. long, evaporated 83·54 cub. ft. of water per hour, from a temperature of 100° Fahr., at the rate of 10·44 lb. of water per lb. of coal, when burning 24 lb. of coal per sq. ft. of firegrate per hour. With a firegrate 6 ft. long it evaporated per hour 98·58 cub. ft. of water at the rate of 10·37 lb. of water per lb. of coal, and burnt 19 lb. of coal per sq. ft. of firegrate per hour. These results were obtained at atmospheric pressure, with the help of a water heater, with good round coal and

without making smoke. The boiler described in this paper, having furnaces 2 ft. 9 in. diameter, would evaporate a larger quantity of water per hour. Such a boiler is found in practice to be capable, provided the steam be applied to a fairly economical engine, of developing 200 Ind. H. P., and 20 Ind. H. P. per lineal foot of boiler frontage, side flues included. A Cornish boiler under similar conditions is capable of developing 16 Ind. H. P. per lineal foot of boiler frontage. This leads up to the important question of the utilization of the steam, which the late Mr. Robert Stephenson defined as its "administration," and fuller information is yet needed as to the comparative advantage of working steam on the compound or single-cylinder principle; also as to the value of steam-jackets, as well as with regard to the initial and terminal pressures most conducive to economy. These enquiries, though full of interest, cannot be entered upon in the present paper; but one of the essentials to economy is the power of raising high-pressure steam steadily and safely, and this may be accomplished by the use of the Lancashire boiler.

At least 300 or 400 boilers have been made, of similar construction and equipment to that described in this paper; and among others it may be mentioned that a series of four such boilers can be seen at the Houses of Parliament, employed for heating and ventilating, which were laid down in the year 1869 by Mr. Joseph Clayton of Preston, who was one of the first to assist in carrying out the views of the writer in getting up a first-class boiler equipment for the service of the members of the Manchester Steam Users' Association.

The PRESIDENT remarked that this was a valuable paper by a very experienced writer; probably many of the conclusions and recommendations were debateable, and he hoped the members would make known their views and experience on the subject.

Mr. FLETCHER exhibited a series of specimens of fractured plates and mouthpieces from the experimental boiler which had been tested by hydraulic bursting pressure as described in the paper. One specimen showed a double machine-riveted longitudinal seam, which had given way at 310 lb. pressure per sq. in., the rent extending longitudinally along the entire 3 ft. length of the seam and nearly 1 ft. beyond into the next plates at the ends of the seam. In another specimen a double hand-riveted longitudinal seam of 3 ft. length had been burst in the same way along the seam by 300 lb. pressure, the rent extending more than 2 ft. into the next plate at one end of the seam. In a third specimen a single machine-riveted longitudinal seam of the same length had been similarly burst along the seam by 275 lb. pressure, but the rent had been stopped at the next plate at each end of the seam. Another specimen was a cast-iron manhole mouthpiece 17 in. diameter inside and 1 in. thick, which had been burst by 200 lb. pressure; the upper portion had been blown entirely off, the fracture running round the cylindrical part of the casting. A cast-iron base of 5 in. diameter inside and 1 in. thickness, for a blow-off tap, had been burst in the same manner by 295 lb. pressure; and a cast-iron base for a 6 in. steam junction valve, with $\frac{7}{8}$ in. thickness of metal, had given way at 275 lb. pressure, a piece having been blown out at one side. A specimen of an oval unguarded manhole, with 17 in. × 13 in. aperture, had failed at 200 lb. pressure by the fracture of the plate at one end of the hole, in consequence of the cover being forced outwards by the pressure. A specimen of a wrought-iron manhole mouthpiece, with 17 in. × 13. in. aperture, such as was recommended in the paper in preference to cast-iron mouthpieces, had sustained 310 lb. pressure without showing any signs of yielding.

He mentioned that the paper had originally been put together in anticipation of the last summer meeting of the Institution in Manchester, as he thought it might be interesting to the members to see the description of boiler that was being very frequently made in that locality. He wished to repeat, as stated in the paper, that this boiler was not put forth as a work of originality; it was one of selection, adaptation, and combination. A great many hands and a

great many different minds had been at work upon perfecting the boiler, and to these he had attempted as far as he could in the paper to do justice by mentioning their names; and if there had been any omission it had been unwittingly made.

The T hoop, the use of which for the transverse seams of furnace tubes was so familiar, had been mentioned in Sir Wm. Fairbairn's report of his researches on the collapsing power of flues, and had been very early adopted, if not introduced, by Messrs. Hick of Bolton; and the welding at the longitudinal joint of the furnace tube had also been adopted by them along with the T seam. Another hoop, of bridge-rail section, for strengthening the flues, had been introduced by Messrs. Hill of Heywood; it was well squared up in the corners, and was similar in section to Brunel's old longitudinal bridge rail.

The raised wrought-iron manhole mouthpiece, shown by the specimen exhibited, had been adopted very early by Mr. Adamson, before it was generally used, and now it was proved to be a very important essential to the safety of the boiler.

The perforated anti-priming pipe, shown in the drawing in lieu of a steam dome, was due he believed to Messrs. Hawthorn of Newcastle-on-Tyne, who introduced it into their locomotives; but in stationary boilers it had been adopted years ago by Messrs. Hick of Bolton, and used very extensively.

The construction of the Lancashire boiler was so very simple that it might hardly occur at first sight that it could develop in working anything at all complicated or of much interest; but it was found in working that there were many minute points of detail which had an important influence on the bearing of the whole, and which were worthy of attention. In illustration of this it might be mentioned that if a boiler of this description, strengthened with flanged joints at each of the ring seams of the furnace tubes, were pressed with a heavy fire, it would be found sometimes to give way at a part where this would hardly be expected, namely at the bottom of the furnace tubes; and the straining and leakage would be more severe in proportion as the end plates of the boiler were more rigid, and as the longitudinal stays were more tight and were

brought down nearer to the ring angle-irons attaching the furnace tubes to the end plates. The reason was that the application of the fire to the upper side of the furnace tube elongated the upper surface, and caused the whole tube to arch upwards; in arching upwards it hinged upon the flanged joints, and tended to open them at the caulking. These joints were generally caulked only on the fire side, and any hinge action taking place there tended to open them just at the line of caulking; this showed the importance of caulking the joints on the water side as well as on the fire side, as was sometimes done. If the ends of the boiler were very rigid, the hogging of the tube was greater. If the ends were elastic, the elongation on the top of the tube righted itself somewhat by thrusting out the ends, and the effect was then divided between the end plates and the tube itself; but if the ends were rigid, the whole of the elongation was absorbed by the hogging up of the tube; therefore the greater the rigidity of the ends, the greater was the stress on the furnace tube, and the greater the risk of leakage. Not long since a case had been reported to him in which the furnace tubes had leaked repeatedly at the bottom in a boiler of that class; the seams were caulked and re-caulked without success, until at length the nuts at the ends of the longitudinal stays were let out; the stays were thus partially released, and the leakage was cured, and it had not occurred again. When the stays were brought immediately over the line of motion or centre line of the tube, and close to the angle iron uniting the tube to the end, then straining would frequently occur at the flanged joints.

Another illustration of the importance of detail bore on the recommendation made in the paper that the safety valves and other fittings should not be all grouped together upon a single mouthpiece, but that each should be fixed direct to the shell independently of the rest. In an explosion which took place at St. Helen's on 18th Feb. 1872, by which four persons were killed, there was a range of five boilers set in a row, each having the safety valves grouped round the steam junction valve. The boiler maker, whilst at work in repairing No. 3 boiler, put in a plug into the steam junction valve; that plug was omitted to be taken out

again, and therefore it would be seen it cut off the communication of that boiler with the safety valves. When the fire was lighted under the boiler, the pressure of steam went on accumulating to a very considerable extent, perhaps 100 or 200 lbs. The result was that the boiler burst, and the explosion was so severe that it injured the adjacent boiler on the right hand and also the one on the left; all three went off simultaneously, or at all events one directly after the other. The fifth boiler—the outer one on the right-hand side—was also so severely damaged that it would have given rise to an explosion, had there been any steam in it at the time. It would be seen that when a plug was put into the steam junction valve in an arrangement of that sort, where there was a series of boilers connected to the same main steam pipe, the safety valve of the plugged boiler might be lifted and it would blow; it appeared outside that all was right, but the valve was really blowing with borrowed steam from the other boilers. Thus there might be a steam pressure of 200 or 300 lb. in a boiler, and yet on opening the safety valve it would blow out as from a boiler with only 30 or 40 lb. pressure, and appear to be all right. Of course it would be said that no one had a right to plug a junction valve, or that, if a plug were put in, it should be taken out again; but it was not wise to make an arrangement which could be thrown into such a dangerous state by the omission of an attendant. It was however in many instances quite excusable to put plugs into junction valves; in many instances it was unavoidable. Suppose a man working inside a boiler; junction valves were seldom tight, and the leakage of steam through them into a boiler standing idle rendered the atmosphere so oppressive, moist, and hot, that the man could not bear it. If he walked underneath the junction valve, the hot water from condensation of steam in the pipe dropped upon him. It was quite excusable to plug junction valves under such circumstances. In testing boilers by hydraulic pressure, if one of a range was being tested, it was necessary to put in a plug; junction valves were not generally made for resisting an upward pressure but for resisting a downward pressure; as soon as hydraulic pressure was applied for testing the boiler, the water would lift the junction valve

slightly, and ooze through, when a violent, local, rapid condensation would take place, a great commotion inside the steam pipe ensue, and a fracture of the pipe frequently occur. The rupture of a steam pipe connected with a range of boilers was eminently dangerous, so that to put a plug in at the bottom of the junction valve was very often a necessity. Under these circumstances it was most important that the safety valves should have a distinct outlet, entirely independent of the junction valve.

A boiler explosion had occurred at Bilston on 8th March 1876, killing four persons, from a somewhat similar cause. The boiler he understood had been found to prime, and therefore a dash plate had been put under the junction valve, to keep the water down; but the rush of steam playing on the dash plate, which was slightly elastic, drew it up, and thus contracted the outlet to the junction valve. As soon as a little contraction took place, the pressure in the boiler increased, and the suction into the pipe increased, until the dash plate soon closed up the opening altogether, or sufficiently so to lead to the accumulation of a greater pressure within the boiler than it could stand, and the result was a fearful explosion. Had the safety valves been directly on the boiler with distinct outlets, no explosion would have occurred. He mentioned these cases, in which several lives had been lost, because the recommendation that a safety valve should have its own direct outlet seemed so simple as scarcely to be worth making.

Another explosion that had taken place at Barrow on 1st Dec. 1875, killing the engineman, had occurred in consequence of the arrangement of steam pipe represented in Fig. 14, Plate 10. It would be seen that the branch steam pipe from the boiler was below the main steam pipe, the object being that if any water got into the main steam pipe it might run back into the boiler; and that was rather a popular view. But when one boiler in a range was laid off while the others were at work the branch steam pipe got quite full of water. This occurred in the present case, and on subsequently starting the boiler to work again, the engineman on unscrewing the junction valve heard a great noise inside the pipe, from the steam forcing its way in through the

water. Hearing the noise, he instantly shut it. The steam had driven the water a little way off; as soon however as he shut the valve, the steam condensed and there was a collapse; the water rushed back like a water hammer against the junction valve, and broke the casing in pieces, as represented enlarged in Fig. 15, which showed the lines of fracture. The water-hammer action in these pipes was not so singular as might be supposed; he had known several cases of fatal injury from the action of the water-hammer, and the branch steam pipes should never be made in that way. Of course the water accumulating in the branch steam pipe under such circumstances could be taken off by the addition of a waste pipe for that purpose, and there had been a waste pipe in the instance of the explosion just mentioned; but the waste pipe was neglected. The arrangements should be radically right, and not dependent upon any little additions of that sort.

The fractured specimens exhibited from the experimental boiler had afforded some valuable information in regard to boiler construction, and had shown him one point he had hardly been aware of, that even a small strong cast-iron fitting block would be a weak point in a boiler; and it seemed clear that with the present high-pressure boilers cast-iron blocks must be got rid of, and the fitting blocks must be carried right through in wrought-iron. In regard to the specimens of plates which had given way along the lines of rivets, he had just had the breaking strain of the metal left between the rivet holes worked out per square inch, and he found that it was 19·9 tons; that is, taking the line of rupture between the rivet holes, which were punched, the value of the metal was there very nearly 20 tons per sq. in. He was having a further set of tests made of the plates from this experimental boiler, with the direct pull of the testing machine, in order to compare the two. The plates of which the boiler was made were from the Snedshill works, Shropshire, and were ductile rather than highly tenacious plates, and he did not think they would be found to carry much more than 20 tons per sq. in. If that proved to be the case, it would show that with a boiler well made almost the full power of the plates was obtained at the riveted joints.

Mr. E. A. COWPER thought their thanks were due to the author for his elaborate description of a good ordinary double-flued Cornish boiler—or Lancashire boiler, if it were preferred to call it so. He thought, generally speaking, the fittings described as being put upon the boiler were such as commended themselves to common sense, and were those commonly used by the best boiler makers. He had seen boilers much worse equipped than this; but a boiler made by a good maker would be found, he thought, to be furnished with pretty much the fittings that had now been described. There were one or two matters in which he did not quite agree with the writer; one was that the gauge cocks were entirely left out, which he did not approve. Whether there were one or two glass gauges, he thought three gauge cocks were useful, and indeed essential, for every boiler. Glass gauges might be broken if the glass was not very good and not very well annealed; it was a very common thing for them to get broken by accident, and then there was nothing left to show the water level unless gauge cocks were provided. There was one little improvement upon the gauge cock which he did not find mentioned, and he referred to it because it was rather curious. If a short piece of pipe were put on to the end of the gauge cock and a small hole made in the end of it, it could always be ascertained at night without a light whether the cock was blowing water or steam, simply by the noise: if it was blowing water, it continued to blow some time after shutting the cock; but if it was blowing steam, the noise ceased instantly on closing the cock.

No vacuum valve had been mentioned in connection with the boiler described; and he considered that was an extremely useful thing for preventing the boiler from filling with water when the steam ran down. If the boiler got cold and the steam condensed, it would fill with water unless a vacuum valve were provided.

The steam dome he thought ought not to be done away with, but the boiler shell ought to be strengthened at that part It was said by the author that the boiler must be necessarily weakened by putting the dome on. That he entirely dissented from; the drawing he exhibited (Figs. 16 and 17, Plate 10,) showed the way in which the strength of the boiler might be kept up at

the steam dome. He never cut away the body of the boiler at all, but simply perforated it with a number of small holes to let the steam pass; as the arc of the shell at the base of the dome was then in balance, having equal steam pressure on both sides, and consequently no longer gave any strength to the boiler in a circumferential direction, though it did in a longitudinal direction, his practice was to fix a straight horizontal stay plate across underneath the base of the dome, as a tie from side to side of the shell, so as to make up the full strength of the shell at that part, this plate also being perforated for the passage of the steam.

Mr. D. Adamson thought that the illustrations exhibited of burst boiler shells showed the necessity for founding the tests on the simple fundamental law that the tensile strength of a piece of iron was in proportion to its sectional area, and that the shearing strength of a rivet was also in proportion to the sectional area of the metal. In these burst specimens it was seen that in every case without exception the fracture had occurred through the line of rivets. He submitted therefore that these tests had been founded on a proportion between the sectional area of the plate and the sectional area of the rivet that was not well considered. Not only so, but before any accurate system of proportion could be hit upon, it must be preceded by an accurate system of tests, those tests to consist first in the quality of the rivet iron. Having ascertained the shearing strength of the metal to be used for the rivets, and also the tensile strength of the plates—if it were found, as he had no doubt would generally be the case, that there was on an average 5 tons per sq. in. in favour of the rivet,—under those circumstances it would be manifest that, to apportion a boiler-plate joint to get the maximum endurance of the plate, the sectional area of the rivet must not be equal to that of the plate left between the rivet holes, but it must be proportionately smaller, in order to arrive at a perfect equality between the shearing strength of the rivet and the tensile strength of the plate. He thought there was also something more than that, and he had often had it brought before him in this way: a manufacturer, and even an engineer, would say that a boiler

should be constructed with a particular diameter of rivet—perhaps the same as in the specimens exhibited, $\frac{3}{4}$ in. Now in his experience as a manufacturer he had found there was no keeping the hole exactly to suit the rivet, and that system of specifying that the boiler should be made with a certain diameter of rivet was a great mistake, and was certainly never carried out in accordance with the true proportions of the plate and the rivet itself. The natural, in fact the universal, tendency was that the punching of the plate was left in a great measure in the hands of the operative puncher or foreman, who said he could get the $\frac{3}{4}$ in. rivet into a $\frac{7}{8}$ in. hole. The disproportion then between the sectional area of the rivet and of the resultant metal became evidently very great: so great that it was manifest in the bursting of the joints in the specimens exhibited they gave no true test of the strength of a boiler joint. In experiments such as these, conducted by means of public funds, he thought the funds ought to be well spent, and that the results of the testing should be of the most demonstrative character, to prove the best possible results that could be secured by the construction of a sound and well-made boiler of accurate proportions, which he had no hesitation in saying was not the case with the specimens exhibited.

For testing the strength of riveted joints it had constantly been the practice to make the trials by using small pieces of plate joined together by three or four rivets only. It was hardly to be expected however that three or four rivets joining a piece of plate for experimental purposes would prove to be very irregular; but in the case of a whole structure, where the punching of the rivet holes was left entirely to the workman, who was sometimes very careless, it was liable to be done in a rude way or to the best of only a poor judgment.

In the paper there were also some statements as to the tests of punched holes and drilled holes, showing something like 5 per cent. in favour of the drilled holes. But it could not be imagined that in an entire boiler more than 5 per cent. of the rivets put into punched holes were perfectly dead true, perfectly at right angles with the plates. Usually the rivets were either at

an obtuse angle or at an acute angle; and as soon as a strain came on such a structure it must be manifest that those rivets which were at an obtuse angle with the plate would come into operation first to take the strain, then those that were truly at right angles, and lastly, if there was anything then left to do, those that were at an acute angle. The rivets at an acute angle indeed could hardly be considered to contribute anything to the strength of the structure, because their angle of attachment was such as not to admit of it; when pulled into the right-angled position they would be slack, and they would have to be pulled to an obtuse angle before they could be equally tight with the rest of the rivets. Instead therefore of tearing such a joint asunder at its maximum power of endurance, it was simply torn asunder piecemeal, one part after another; the obtuse-angled rivets held first, the truly right-angled ones next, and certainly the acute-angled the last.

It had also been said, and he thought with a good deal of belief, that a punched hole was better than a drilled hole on account of being slightly conical by the action of the punching. But taking a rivet of say $\frac{3}{4}$ in. diameter in the middle, it would bear a shearing strain corresponding to that area, and the increased diameter at the ends could not add one fraction to the strength of the structure; but on the other hand that increased diameter of the hole greatly detracted from the strength of the plate; the strength of the structure was therefore necessarily diminished just in proportion to these two irregularities.

The present Lancashire boiler described in the paper had been stated by the author to have been the work of many minds; in that view he quite concurred, and also in giving all credit to Sir Wm. Fairbairn for the introduction of the two-flued system in place of the single flue that had been the practice before his time. The subject of the paper being somewhat of a historical character, he might allude to the fact of the flanged seam for the internal flues having been introduced by himself in 1851; and it was now mostly used by all the best boiler makers. About that time also, as far as he himself was concerned, a radial junction pipe had been used for coupling the steam nozzle on the boiler to the main line of steam

pipe. Gusset stays had been introduced by Sir Wm. Fairbairn at the same time as the two-flued boiler, he believed; at any rate they had been used by himself in 1852. He had only last month removed a boiler constructed upon this type, which had been in use since 1855 at the works of Messrs. Thos. and R. Eccles, Lower Darwen, having flanged seams and gusset stays and two longitudinal stays; so that in these respects the construction described in the paper was one that had been a very long time in use. As early as 1856 he had constructed boilers of that type for Messrs. Hopwood and Sons, Blackburn, to work at 100 lb. pressure, and as far as he knew they had them still.* He wanted to make a little historical statement, which he thought it was desirable should be properly understood. He did not wish to detract one fraction from the greatness of Sir Wm. Fairbairn, or from the grand qualities he possessed to pursue everything to a demonstrative conclusion; he believed he was speaking the sentiments of everyone in giving him credit for being the father of demonstrative evidence, taking nothing for granted about the iron structures of the country. In 1857 however, when the investigation of the strength of flues was entered into, the flanged seams had already been working under his (Mr. Adamson's) own control for six years; at that time he had constructed 193 boilers with sectional lengths of flues, upon the principle that the strength was approximately inversely as the length. The length of each section of the flue between the flanged seams was so proportioned, that in case of a flue accidentally getting hot and sinking down, the sectional area of the plate and the strength of the flanged seam should be sufficiently large to resist any further collapse, whatever was the shape the plate might be in; and probably the water would be able to rush over the sunk place, and prevent it from being weakened by further overheating. He had had several cases of that sort, with test tubes that had been made by himself at his own cost, and tested at Longsight by Mr. Longridge, by whom they were ultimately submitted to Sir Wm. Fairbairn; one of these tubes containing three flanged seams was still preserved at his works, showing how it had been indented by the pressure without an entire collapse.

* It has been ascertained that these boilers are now working.

The principle that he had calculated the proportions on was that the sectional area at the root of the flanged seam should be equal to any strain that could be put upon it; after a partial collapse the strain upon the flanged seam became one of tension instead of compression, and on a second testing the tube had resisted even a greater pressure than in the first case, without tearing through the metal at the root of the flange. So that he had reason to conclude that a flue wisely constructed with flanged seams not too far apart, dependent upon the pressure to be used, would protect itself against failure even under the most calamitous condition of getting overheated through want of water. He had tried to be just, and to give an exact and accurate record of the part he had taken in the matter, and to show that the investigation was not an original one when it was put forward by Sir Wm. Fairbairn. He regretted only one point—that his own investigation had not been acknowledged by him, and had not even been referred to, except by calling the flanged seam a rigid joint. He thought it was hardly a fair description to call it a rigid joint; it was a great deal more, because as the water was on both sides of the flange, the rivets were protected in the water, and it was thus a seam that could bear a great deal more intense fire than any joint that had been introduced into boiler manufacture before or since.

In reference to the testing of boilers, and also to the necessity to some extent of staying them, and to the uniform development of security, it had been stated in the paper that it was not necessary to make the transverse seams any stronger than what could be secured by single-riveting; and in a former report by the writer it had been urged that the bursting of a new Lancashire boiler by frost proved that the transverse seams did not suffer in a boiler of that class, the longitudinal seam having been burst by the expansion of the water in freezing. This so far proved the statement made, but there was this difference that a boiler did not work with freezing water; it worked with the steam up, which had a tendency to produce a great deal of mechanical action from the unequal heating and expansion, and that mechanical action caused longitudinal strain on the boiler; and there was a greater strain from this cause

on the transverse seams in the Lancashire boiler than in the Cornish boiler. He held it therefore to be not an unwise thing to protect the structure by getting as near a uniformity of strength in the shell as it was possible to get, even at the expense of chain-riveting for the transverse seams.

It was also stated that the longitudinal stays were not necessary; but he held that in the case of accidental conditions arising, in which the boiler might get injured, the longitudinal stays became a great source of security. He quite agreed in considering that the elasticity of the end plates was a very important point; at the same time he thought the longitudinal stays were of more value than might at first sight appear, as their effect was to give solidity and strength. In a Lancashire boiler of the dimensions represented in the drawings, about 30 ft. long, with ten ring seams, and having two longitudinal stays of the size there shown, which would probably carry a tensile strain of 100 tons each before breaking, it was not only that the strain of 200 tons could be taken off the end plates and shell plates by the two stays, but there was that amount of relief at every ring seam. That he thought was a fair way to look at the question; and it appeared to him a wise precaution to keep the longitudinal stays in boilers of that class.

The very serious explosion at Blackburn, which had been alluded to in the paper, suggested some important subjects for examination. The average tensile strength of the plates in that boiler was given in the paper as 20·4 tons per sq. in. Some tests on that occasion had been made by himself for Mr. Fletcher, and he wished to call particular attention to the results, to support the position that it was far more important to secure high elasticity than it was to secure high tensile strength. Some of the plates no doubt took a strain as high as 26 tons per sq. in. to pull them asunder; but these were Lowmoor plates out of the fire-tube of the boiler. Where the shell burst, the plates pulled asunder with about 20 tons per in. with the grain, and one piece with punched holes as low as 15·92 tons across the fibre. That being the weak link of the chain, he held it would be a misfortune to let it be supposed that that boiler had possessed anything like an average endurance in its

metal of 20·4 tons per sq. in., when the strain to pull it asunder was reduced in one place to only 15·92 tons. The same argument applied, whether the plates were riveted with punched holes or with drilled holes. These tests he thought established the principle that the plates ought to be tested especially across the grain; because, that being the weakest direction and therefore the measure of the strength of the structure, the sectional area of the metal between the rivet holes ought to be proportioned to that low strain. The shearing strength of the rivets, when proper rivet iron was used, might be taken according to his experience at as much as 24 tons per sq. in., and the tensile strength of the plates across the grain at 17 tons; and taking that view it was manifest that the sectional area of the plate left between the rivet holes ought to bear to the rivets the proportion of 24 to 17; if it were anything different from that, the joint must necessarily be deficient of the full strength attainable. Since 1853 he had adopted without an exception the chain-riveting system for longitudinal seams, and it had now become universal.

For the introduction of the wrought-iron manhole mouthpiece on stationary boilers there was but little credit due to himself, because locomotive engineers had never used anything else than the wrought-iron manhole for their boilers, so that it must be of old date. When he was entirely engaged in locomotive engineering, up to May 1849, he had never riveted a cast-iron manhole on a locomotive boiler: the manholes were all made of Yorkshire angle-iron. It had been satisfactorily shown in the paper and proved by the author's experiments that most of the cast-iron mouthpieces and stands for fittings were the weakest points. In the very large number of stationary boilers made by himself during the last twenty-five years he had never fixed any mountings on them except in the way shown in the drawings; so that this certainly was not a very new thing. It had been his misfortune at times to have them pulled asunder and broken like the specimens exhibited, and sometimes not in a very desirable way; often the fracture had shown that the metal itself was at fault, and if the defect could have been known beforehand it would have been rejected as an imperfect casting, not suitable to be put on a high-pressure boiler.

The wrought-iron mouthpieces had formerly been adopted by himself for 80 lb. pressure per sq. in. and upwards, but he now adopted them from 70 lb. upwards. Up to 65 or 70 lb. pressure he considered cast iron in most cases might be fairly used for the mouthpieces as being a creditable and comparatively dependable material. In his own practice of late years, instead of reducing the strength of the boiler shell at the manhole mouthpiece, he had increased the sectional area of the metal by a double thickness of plate, riveting an additional plate inside the shell at this point, passing 6 or 8 in. beyond the range of the manhole mouthpiece rivets, taking care that the strength of the shell was not injured by more rivets than existed in a longitudinal seam at any one point. The tests now exhibited not only showed that the cast-iron manhole mouthpiece gave way, but the shell plate itself on each side of it up to the adjoining circular seams, illustrating that additional metal at this part was necessary, to secure anything like uniformity of resistant power. He need not say more about this subject, because the Lancashire boiler was well understood, and Mr. Cowper had explained another plan that he had adopted to keep up the strength of a boiler shell at the junction of a steam dome.

One result of this discussion he trusted would be that the drill would do the work instead of the punch, so as to get an exact and established condition, whereby the ultimate strain on the plate could be depended upon to a fraction, without its strength being impaired by needlessly increasing the size of the rivet hole. Not only so, but when the structure was put to work the whole of the rivets without an exception would take their portions of the strain at the first, and the greatest possible strength would be obtained from the structure. Many precautions apparently had been taken in investigating the strength of the experimental boiler described in the paper; many points had been brought prominently forward which he could not recommend; and he thought it had been somewhat remiss that a more accurate view had not been taken of the construction of the riveted joints, as there had been frequent opportunities of seeing the system of drilling at his own works; and it would have been prudent to make a further investigation, to

get the best possible structure to test. He had himself seen sufficient boiler testing to believe that the time was not far distant when the whole boiler work of this country would be compelled to have drilled rivet holes.

Mr. BENJAMIN WALKER mentioned that some six or seven years ago, with a view to ascertain the relative value of drilled holes and punched holes to ensure the thorough union of two wrought-iron plates riveted together, he had adopted the simple experiment of taking two strips of plate, some 6 or 10 in. wide, and punching a number of holes in them with the usual accuracy, and riveting them in the usual way with hot rivets; he then took another similar pair of plates, and had the holes drilled with accuracy and the rivets put in cold. The riveted plates were no heavier than a man could lift very well, and holding one end he beat the other end upon the anvil until the two strips were broken asunder along the joint; the punched joint went to destruction very speedily in comparison with the one where the holes were drilled and accurately fitted. There could be no doubt that if the whole structure came into strain at the beginning, not one part following another as Mr. Adamson had described, it must be stronger; and he considered it a complete mistake to speak of a punched hole being equal to a drilled hole. Whether the users of boilers would pay for the holes being drilled and for the work being accurately done was another matter; but that the work itself was better he was quite sure. With regard to the rivets being taper in punched holes, in consequence of the holes being wider on one side of the plate than on the other, so that the rivet was smaller at the middle than at the end, this must evidently be wrong, because the plate was weakened without giving additional strength to the rivet.

Several years ago, when he had been advised to join a boiler insurance association and to adopt a boiler of the Galloway pattern, he had declined the assistance offered in the way of inspection, but took the particulars of the boiler recommended, and had one made exactly to the dimensions given, and at the same time had a Fairbairn (or ordinary Lancashire) boiler made to work alongside it,

having the same heating surface; the latter boiler had six solid T iron rings round each flue, attached to the flue by rivets and washers at every 8 in. round the circumference. The two boilers were worked week and week alternately; and he found from this careful experiment that the common Fairbairn boiler would do just as well as the other. The two boilers had been at work fourteen years, and he did not think that either of them was practically any the worse for use. Seeing that it gave as much steam, he should prefer to take the common straight-flued boiler without any complications, as he preferred the plain straight line for the flues. The boilers he referred to were made 28 ft. long, and he agreed with the author of the paper on that point, that 28 ft. was long enough for a boiler having two flues of 2 ft. 9 in. diameter; if the boiler were to have smaller flues it should be shorter.

With regard to longitudinal bolts through the boiler, for the last fourteen or fifteen years he had never made a large boiler without putting in two bolts, as he thought they were a great safeguard for holding the whole thing together. They could not do harm, because the spring of the end plates could still take place between the bolts and the ends of the flues. They formed a general stay, and prevented the whole boiler from being strained, adding very much in his opinion to its durability and safety.

With regard to cast-iron mountings, he thought the specimens exhibited had been burst because they were made of bad material or badly put on; he had himself made large numbers of them, and had never known one burst. He believed if the matter came to be investigated it would be found in cases of fracture that the mountings had been badly put on. If the cast iron was not well fitted to the wrought iron, the casting would be partly damaged in the process of fixing, before the pressure was on; and it then only required a few years' contraction and expansion for it to come to pieces. In the fractured specimens exhibited he believed that if the castings had been made of proper metal and properly riveted to the shell, they would not have burst, even with 50 lb. higher pressure.

The PRESIDENT enquired whether in the experiment mentioned with punched and drilled holes any influence was attributed to the difference in the riveting, one being done hot and the other cold; and also whether it was the plates or the rivets that failed.

Mr. BENJAMIN WALKER could not say whether the plates or the rivets failed; he could only say that the two pieces which had been riveted together came asunder, and when they were riveted cold with drilled holes they were kept better together than when they were riveted hot with punched holes. The punched holes had the common clearance of 1-16th inch to get the rivets in; but in the drilled holes the rivets were got in as large as possible.

Mr. L. OLRICK observed that the paper contained an accumulation of useful facts which might even be serviceable to boiler makers and engineers; but there was also another class—the boiler owners—by whom he was very desirous for the paper to be read. Most boiler owners would not believe in the value of the different improvements made one after another, because each was attended with additional cost. Therefore he considered the author was correct when he said that, if first-class boilers were laid down instead of low-priced ones, the scientific boiler-maker would have fairer scope, the steam user would derive economy, and the public would be benefited by the prevention of explosions. That meant that the boiler owners must pay a higher price for first-class boilers; and he was sure there were boilers made of the same size as that shown in the drawings, but with none of the improvements there represented, which could be purchased at two-thirds or less than two-thirds of the price of such a boiler as was turned out by the best makers. Few boiler owners could understand how it could pay to give such high prices; it was only experience that would prove to them that the author of the paper was right in recommending the best boilers that could be made.

In reference to the testing of boilers, it had been said in the paper that a boiler of the description shown in the drawings, 30 ft. long by 7 ft. diameter, should be tested by 150 lb. hydraulic pressure,

the working pressure being 75 or 80 lb. That was what he should call an excessive test pressure. At Messrs. Galloway's works and at Mr. Adamson's works he had seen four boilers of those identical dimensions tested, but none of them with more than 120 lb. pressure for a working pressure of 80 lb., so that the test was 50 per cent. over the working pressure; and this proportion of test pressure to working pressure corresponded exactly with his own practice. Very likely the author in his experience had found that sometimes by excessive pressure a flaw had appeared in some part of the plates or some part of the riveting, and that afterwards, as a flaw never got smaller but always increased, it had been the cause of one of those explosions that could not easily be explained. He thought the practice was to be condemned of having an excessive test pressure, such as was used in France and Prussia, where boilers were tested not merely with twice but even with three times the working pressure; the consequence of this was that the boilers were made simply to stand that high test pressure, and were really suitable for a much higher working pressure.

With regard to longitudinal stays, he agreed in thinking that they should be used in the manner shown in the drawings; but there was one point that had not been mentioned, and it was an essential one—that the gusset stays should be made to do the work first, and the longitudinal stays afterwards. That could be done by putting a large washer underneath the internal nut, and screwing the nut up as hard as possible, and then simply screwing up the external nut. By that means the longitudinal stays would only come into use after the gusset stays had taken the brunt of the work, and they would be an additional security to fall back upon when the others were insufficient.

By looking at the specimens exhibited which had burst, he thought many valuable corroborations were afforded of what had previously been known, or had been suspected but had not been quite surely ascertained. There might have been faults in the castings which had given way, but that was not so much the question as the best means of properly strengthening what had been called

in the paper an unguarded manhole. His own practice in vertical boilers always was to rivet round the manhole a wrought-iron ring 4 in. wide, $\frac{7}{8}$ in. or 1 in. thick, fitted down carefully to the boiler plates. This gave the advantage that a smaller manhole could be used, because there was an additional difficulty in getting into a vertical boiler when there was a large projection of the mouthpiece outside. He suggested that it would give additional value to the experiments accompanying the paper if a similar trial were made of that kind of manhole, strengthened in the manner described. There was also another point that struck him: the boiler shown in the drawings was weakest longitudinally; therefore why not, instead of having the greatest length of the manhole longitudinally, make it the other way, crossways? Then it would extend a smaller distance in the direction in which the boiler was weakest.

The description given in the paper of the mudholes and how they ought to be made was confined to the double-flued or Lancashire boiler; but in the Cornish boiler great difficulty was experienced in getting a proper mudhole at the bottom, unless the flue was raised excessively high. The mode that he adopted of getting over that difficulty consisted in fixing on the bottom of the boiler at the front end a large pocket made of Lowmoor plate, and attached to the front plate of the boiler, which was carried down for the purpose; this gave plenty of room for a large mudhole in the front plate, and the blow-off cock was fixed in the bottom of the pocket. By this means several advantages were obtained. The difficulty of having a blow-off cock at that part of the boiler in the ordinary construction was well known, and it was very difficult to replace a plate at that part. But by this plan the plate forming the pocket could at any time be replaced when requiring renewal, without interfering with the rest of the boiler; and the large mudhole in the front plate gave ample room to examine as far as possible the bottom of the flue and the bottom of the shell inside; also the pocket served as a receptacle, in which the greater part of the sediment from the water would collect, for blowing off through the cock or cleaning out through the mudhole. This he thought was superior

to the ordinary plan of putting two small mudholes half way up in the front of the boiler.

With regard to steel plates for furnaces, it had been stated in the paper that these had been attended with great advantages, but the kind of steel had not been mentioned. That he thought was a point of some importance, and he presumed it was mild carbonised steel of very small tensile strain, so that it was not brittle; the question of tensile strain of course would not come into consideration at all for the furnace plates, as they were subject only to external pressure.

For the shells, "best best" iron had been recommended in the paper; but the expression "best best" was somewhat vague. He had for many years used "B B H" Bloomfield iron for boilers, and had never had to return a single plate of that brand, but he had returned several defective plates of "B B H best best." In the manufacture of the plates of higher quality it seemed that somehow or other the men either had not had sufficient experience or did not give the requisite attention.

With regard to the vacuum valve which had been mentioned, there was one point he hardly understood—how the feed water could flow into the boiler in the event of a vacuum inside it, unless the feed-pipe and valve had been left open so that there was direct communication with the water main.

With reference to the safety-valves, it had very properly been pointed out in the paper that there was great additional safety in employing such a valve as the Cowburn valve shown in the drawing. Other contrivances had also been mentioned, and he had himself used one that was called Smith's sentinel, a small instrument having a steam whistle on the top of a high pipe. The moment the working pressure was exceeded, steam was emitted through the whistle, and the fireman could not interfere with it or stop it; the attention of the boiler owner or works manager was thus immediately called to the fact that the boiler was working under excessive pressure, over and above the working pressure at which the safety-valve was set. As affording additional safety he thought this instrument was to be recommended.

In regard to feed-water heaters, he wished to ask whether in addition to their other advantages it was not also found that they were convenient receptacles for the sediment and scale that would otherwise go into the boiler. At a certain temperature the sediment contained in water was thrown down; consequently if the feed-water heater heated the water to that temperature before it got into the boiler, it retained the scale that otherwise would lodge on the heating surface of the boiler; thus another advantage was added to those mentioned in the paper.

The statement that such a boiler as the one described in the paper was found in practice to be capable, provided the steam were applied to a fairly economical engine, of developing 200 Ind. H. P., was one in which he could not agree; the remark was qualified by saying that the steam should go into a fairly economical engine; but he objected to the statement that a boiler developed any indicated horse-power whatever. It evaporated a certain amount of water; but what was done with the steam evaporated from that water depended entirely upon the engine, as implied by the qualification made in the paper. When however the indicated horse-power of a boiler was spoken of, it could not be wondered that boiler owners should ask what power a particular boiler would indicate. If it were replied that this would depend upon what engine was employed, they did not believe it, and thought it must be the fault of the boiler, and not the fault of the engine, if the desired power was not obtained. He thought therefore that that mode of expression was misleading.

The valuable experiments made by the writer of the paper he hoped would not be confined to horizontal boilers, but would be extended to vertical boilers, of which there were many under inspection. In vertical boilers there were surfaces—for instance the surfaces at the top, the crown of the boiler itself, and the crown of the firebox—which he considered ought to be flat and not curved, so as to be far more elastic. But to deal with large boilers of that description was treading on dangerous ground, because hitherto very few reliable experiments had been carried out upon them. He thought therefore it would add to the value of the paper

if the author would extend his observations to vertical boilers, and to flat and curved surfaces such as the flues and firebox in vertical boilers; because when such surfaces were very short and of large diameter it was often a question whether it was not practicable to save a number of stays, as compared with those in locomotive boilers. It was of course easy to calculate the number and size of stays to be applied to flat surfaces, but with curved surfaces it was not so easy to get at the most economical way of applying the stays.

Mr. JEREMIAH HEAD thought the author had hardly had sufficient credit for the great pains he had evidently taken in working up the paper, and for the enthusiasm with which he had devoted himself to his subject. If in no other way, he had done good by raising a discussion upon boilers; for if there was one thing more than another that every mechanical engineer thought he did know something about, it was a boiler. Many of the remarks made in the course of the paper carried conviction with them. What was said about the necessity of substituting wrought iron for cast iron around manholes and mudholes was conclusive at all events to his mind; also what was said about the harmlessness, in the way of weakening the boiler, of fixing the safety-valves and other fittings in separate places, instead of all on one casting. There were several valuable remarks on minor points, such as the importance of keeping the non-conducting composition clear of the joints and fittings, so as not to conceal leaks; the desirability of carrying the steam junction pipes in a circuitous course, so as to avoid breakage from expansion; the objectionable nature of diaphragm joints, which were really equivalent to the introduction of two pistons forcing the pipes asunder, therefore doing more harm than good; and the advisability of making the steam pipes with a downward inclination from the boiler, instead of draining towards it as was the usual custom, so as to prevent the possibility of a store of water accumulating in the pipes. The object of the paper seemed really to be to advocate better work in boiler making, and therein he thought the author would have the support of all. But he was inclined to think that more had been proved than had

been intended: the remarks about what happened directly a fire was put into the boiler,—about the frequent collapse of tubes if the water got low,—about the hogging of the flues,—and about the extreme care needed in setting a boiler,—these remarks could hardly be read without inducing a feeling of nervousness about the Lancashire boiler altogether, and impressing the idea that if the greatest pains were not taken with every little detail—pains which it could hardly be expected would be universally taken—the boiler was at best a dangerous implement.

The question therefore arose, whether the Lancashire boiler now described was the only kind of steam generator to be recommended. The paper had certainly ignored all others, perhaps because the author's space was limited; but he could not help feeling that there were other forms of boiler, such as some vertical boilers, in which these dangers were considerably lessened. He mentioned this, having under his own care nineteen vertical boilers with fiercer heats through them than were dealt with in any Lancashire boiler; and having had these working many years without any explosion and without any strainings or any trouble worth speaking of, he felt some confidence in saying that the Lancashire boiler was not the best type of steam generator, and in predicting that it would come to be largely superseded. The nineteen vertical boilers that he referred to were made with a single flue right through in the centre, without gussets or stays of any sort, but with a number of cross tubes in the flue; and they gave excellent results. They were all fired from furnaces which were also employed for the heating of iron; but there was no reason why an internal firebox to be fired in the ordinary way should not be applied. He had recently had constructed two such boilers, each 20 ft. high and 5 ft. 7 in. diameter; and in experiments made to ascertain their evaporative power, measuring the water by a meter as it was pumped into the boiler, it had been found that the boiler evaporated $46\frac{1}{2}$ cub. ft. per hour, the water being fed in at 170° Fahr. During a three hours' experiment when there was no interruption 1 lb. of coal evaporated 10·4 lb. of water; afterwards during the dinner hour the grate was cleaned, and the experiment was

continued through the day, the result over the whole day being 9·33 lb. of water per lb. of coal. The rate of consumption of the coal was slower than that mentioned in the paper, being only 10 lb. per sq. ft. of grate per hour; the coals were of a sort known in Durham as Ivesley coals; they were small, and rather damp owing to rain at the time of the experiment. The boiler weighed about 8 tons, and the cost, including all fittings, chimney, gallery, damper, and firebars, was £327, or £41 per ton; it appeared from the paper that the Lancashire boiler cost £27 10*s.* per ton with fittings; but the vertical boiler had been ordered in December 1873, when everything connected with boiler work was very high in price.* He was informed by the owners of the boiler that so far it had given but little trouble, the only occasion being some leakage at the top angle-iron, which was afterwards repaired.

The advantages of a vertical boiler over the Lancashire type were that it did not occupy above one tenth of the floor room, and did not require above one tenth of the roofing. There was no brick chimney; the weight and cost he had given included a wrought-iron chimney lined with bricks, therefore there was no separate chimney to pay for. There was no seating of any sort, except that the boiler was set upon a cast-iron plate on concrete. There was no straining, because the whole of the firebox and flues were heated equally, and as they expanded they simply bulged out the top plate a little, and that might go backwards and forwards without doing any damage whatever; there was of course no hogging of any sort. There was sufficient room for a man to get in between the flue and the inside of the shell all round for examination; but in the Lancashire boiler there were certain parts where the space was so confined, that a man could not get to examine. There was no external corrosion in this vertical boiler, because there was nothing hidden; it was covered with a thick coating of composition, which in case of a leak became soft and revealed the defect. There was no chance of bursting, because no part exposed to the fire was in tension except

* The cost of the same vertical boiler at present prices has been ascertained to be about £242 complete as above, equivalent to £30 6*s.* per ton.

the cross tubes inside the flue. The outer shell not being exposed to fire could be made butt-jointed with a fish-plate inside and out, the rivet holes being drilled; this was perhaps the strongest form of joint that could be made, but on account of the three thicknesses of plate it was inadmissible for surfaces exposed to the fire. With such a boiler there was little chance of bursting; and even if bursting should take place, there was comparatively little danger, for it was probable that the boiler would hardly move from its place, from the want of something to react against. But in a Lancashire boiler or any boiler laid down on its side, if it burst it had the ground to react against, and would probably fly up and displace a large amount of material; and if it was covered with bricks, like the boiler shown in the drawings, in case of an explosion every brick became a bullet. Then again there was no danger from the water getting low in a vertical boiler; the water level might vary a couple of feet and do no harm; in the boilers 20 ft. high the average water level was 5 ft. from the top. The aim in designing this boiler had been to put so much heating surface above the fire that the flame should be entirely killed before it got to that part of the uptake where it went through the steam space. He had so far succeeded in this, that having in one case put in a short pipe from the outside shell to the flue, to look in at, he could see no flame whatever when the boiler was being fired as hard as possible in the firebox; he left a small piece of nail-rod in the pipe for many weeks projecting into the flue, and found it was not even scaled during that time. The cross tubes in the flue above the water level had a tendency to dry the steam, but he doubted if the steam was ever superheated, because being in contact with the water it would probably saturate itself and make more steam. A boiler of this sort could be put up very quickly, because there were no foundations to prepare; it was self-contained, so to speak. If a large number of boilers were required, as in the case of driving a large mill, it would probably be best to arrange what might be termed a battery of say eight of these boilers in the form of an octagon round a central high brick stack, with a roof something like an umbrella radiating from the chimney; this would be a compact

arrangement occupying very little room. It would be observed that the outside shell of this vertical boiler was not more than 5 ft. 7 in. diameter, against 7 ft. minimum diameter of the Lancashire boiler described in the paper, which had been stated to be suitable for a pressure of from 75 to 100 lb. per sq. in., according to whether the plates were 7-16ths or 9-16ths in. thick. A vertical boiler 5 ft. 7 in. diameter would always stand 20 or 25 per cent. more pressure than a 7 ft. Lancashire boiler with the same thickness of plate; therefore if higher pressures were to be used, it would obviously be desirable to give up two flues, and have a boiler of some sort with a single flue. He had a strong impression that to continue to use boilers laid down on their sides and of very large diameter with two flues was to adhere to an old type from fashion, rather than to consider the fundamental principles on which boilers should be constructed.

The PRESIDENT enquired what was the number and diameter of the cross tubes in the vertical boiler now described, and how they were cleaned.

Mr. HEAD replied that there were fifteen cross tubes in the furnace and uptake, those in the uptake being tapered from 7 to 9 in. diameter, and those across the firebox about 9 in. They could be cleaned from the inside of the boiler, and the soot deposited on them externally was disposed of by a small quantity of gunpowder once a week. The furnace was 5 ft. diameter inside at the bottom, tapering to 2 ft. 9 in. diameter at a height of 5 ft. where the uptake began; and to examine the inside of the boiler a man got in between the 5 ft. 7 in. diameter of the outer shell and the 2 ft. 9 in. diameter of the uptake.

Mr. C. COCHRANE observed that allusion had been made to the external corrosion of boilers, but not to the internal corrosion which took place owing to the acidity of the water. He had himself seen this take place at the water level in an ordinary cylindrical boiler laid flat, to such an extent that in a recent case that had come under his notice the boiler had to be rejected, in consequence solely of the

internal corrosion. A feed-water heater he found was being introduced, based on the principle of absolutely throwing away all the pure water that was condensed from the engine, because it contained this acid property of corrosion; the heater being warmed by the escaping steam, which was condensed, heated much more feed-water than was necessary for the engine supplying the steam; and it struck him that this was going in the wrong direction, to incur the trouble of condensing the steam in that way, and then throwing away the pure condensed water thereby obtained. The acidity of the water could be corrected, as at his own works it was corrected, by the use of caustic soda introduced into the water before it went into the boiler.

Mr. W. S. HALL pointed out, in reference to the relative strength of boiler plates and rivets in cross section, that with the proportions given in the paper for the double-riveted longitudinal seams the strength of the plates along the straight line was 30 per cent. less than along the zigzag; consequently it was not surprising to see that in all the burst specimens exhibited the fracture had gone in a straight line, instead of following the zigzag. The fracture would never be got to follow the zigzag until the section was so equally proportioned that there should be no reason for its following the straight line rather than the zigzag; and unless this was done the full benefit of double-riveting would not be attained. If the rivets were pitched at $3\frac{1}{8}$ in. longitudinally, retaining the 2 in. pitch in zigzag, the tearing section in line or in zigzag and the shearing section of rivet would be practically the same, due allowance being made for a slight rimering of the holes, the rivets being $\frac{3}{4}$ in. diameter and the plates 7-16ths in. thick.

Mr. E. J. C. WELCH observed that allusion had been made to the rough manner in which boiler plates were punched for riveting; and no doubt when the plates were wholly punched and guided in the machine by a man there was great liability to err; but that was got over by the use of the automatic dividing table now employed at several works, by which the plate was punched at

exact distances. There was a differential adjustment to the table to enable the holes in the smaller diameter of the boiler to be spaced nearer to one another, thus allowing for the rivets going in a radial direction when the plates were bent. But even that would never approach at all to the advantage gained by drilling. In a large series of tests made in the present year by Mr. Kirkaldy on drilled and punched holes of the same nominal diameter, in plates of the same description in every case—all being the best known English brands—it had been found that with punched holes the loss of strength was 8·7 per cent. more than that due to the material removed, and the elongation of the holes at rupture was only 7·65 per cent.; with the drilled holes the loss of strength was only that due to the material removed, and the elongation of the holes was just double, namely 15·8 per cent. Testing the plate in the direction of its being rolled, the ultimate tensile strength of the *punched* plate, estimated upon the entire width of the plate, without deducting the rivet holes, which were the same in both cases, was 23,299 lb. per sq. in; and of the *drilled* plate 27,982 lb., or more than 20 per cent. stronger. Crossways of the plate the strength was 22,063 lb. with the *punched* holes, and 25,600 lb. with the *drilled* holes, or about 11 per cent. more; so that these experiments showed a very great advantage in favour of drilling. But he thought the advantage did not stop there; the drilling of holes in the workshop induced greater care on the part of the men than the old rough process of punching them; secondly the iron removed from the plate was only that necessary for the admission of the rivet, the diameter of the drilled hole being no greater than the smaller diameter of the tapering punched hole; and thirdly the iron surrounding the hole was not damaged by the drilling, as it was by the punching, as these tests clearly proved.

With regard to steam junction pipes being broken by the water lying in them, he had witnessed a case of that sort in Manchester not very long ago. A 6 in. steam pipe about 100 ft. long, draining towards the boiler, had become filled with condensed water at the lower end, when the boiler was standing; the steam was not got up till the middle of the day, and when the man opened the valve, the water was thrown to the far end of the pipe, which was closed

by a blank flange, and the pipe was torn asunder by the blow with an explosion like that of a gun going off.

Referring to the sentinel low-water alarms, which had been mentioned, the best of them he thought were little better than toys. They did very well when they were new and properly fitted up, and made to work frequently for exhibition to people looking at them; but they were essentially instruments which were not constantly at work, as they were only supposed to act under certain circumstances at very long intervals, and in case of the neglect of the man in charge of the boiler. They thus came to stick fast and get clogged up and otherwise thrown out of proper working order; so that they were not to be relied upon, as a very great number of them failed. There was the case of one which had recently been introduced, which when fixed to some boilers was found in the morning to have emptied them.

The strength of the internal flues in a boiler was certainly an important matter, and one which had not received the amount of attention which it demanded. Boilers were frequently met with in which the strengths of the shell and of the flues were altogether at variance. Sir Wm. Fairbairn had established a rule from a series of experiments in which he had shown that the strength of the flue varied inversely as its length and diameter, and in direct proportion as the thickness raised to the power of 2·19, and multiplied by the constant 9,675,600, all the dimensions being taken in inches; his rule for the collapsing pressure of a flue, whose length was taken in feet and diameter in inches, became therefore

$$\text{Collapsing Pressure in lbs. per sq. in.} = 806{,}300 \times \frac{(\text{Thickness in ins.})^{2\cdot19}}{\text{Length in ft.} \times \text{Diam. in ins.}}$$

The Board of Trade had adopted a rule slightly different, in which instead of taking the same power of the thickness, which needed the use of logarithms to develop, they took the square of the thickness, multiplied by 90,000, and divided by the product of the length plus one, multiplied by the diameter, to give the safe working pressure, which was assumed to be one sixth of the collapsing pressure; their rule was therefore

$$\text{Working Pressure in lbs. per sq. in.} = 90{,}000 \times \frac{(\text{Thickness in ins.})^{2}}{(\text{Length in ft.} + 1) \times \text{Diam. in ins.}}$$

The PRESIDENT remarked that these rules could only apply within certain limits of length, and he enquired what was the limit of length within which they were intended to be employed.

Mr. WELCH said the Board of Trade rule was intended for application to marine boilers, for which in practice the limit of length was 10 to 15 ft. But in ordinary cylindrical boilers there was a difficulty in ascertaining what was the "length" of flue to which the rule was applicable. Sir Wm. Fairbairn in making his experiments had assumed the flue to be one plain flue the whole length of the boiler; but flues were now commonly made flanged at about every 3 ft. of their length, and the question was, what was the strength of that flanged seam to resist collapse. Sir Wm. Fairbairn suggested the dividing up of the flue into a series of short lengths, with a hoop round each, without however stating the strength of the hoops; and if their strength was not stated, the rule became utterly useless, because unless the hoops were strong enough to prevent collapse, the flue and hoops would all collapse together. It would be interesting to know what strength the writer of the paper attributed to the flanged seam shown in the drawings; and whether he considered that, in calculating the collapsing pressure of flues constructed with these seams, they might be considered as being of a length equal to the distance between any two *adjacent* flanges, or whether they should not be considered as of a length equal to the distance between two *alternate* flanges, namely 6 ft. instead of 3 ft.

With regard to the pressure to which the boilers were tested, it seemed to him that no hydraulic test of less than double the working pressure should be considered satisfactory for any boiler. If the boiler were properly made, it would not be injured by that test; because as long as any material was tested within its elastic limit it returned to its original condition; and it was to be supposed that no boiler would be made, whose elastic limit was less than twice its working pressure.

Mr. C. C. WALKER said there was one point which ought not to be lost sight of, and that was the question of priming, which was

a great bugbear, to say nothing of its danger. A question had been raised respecting steam domes, and there was no doubt that they were dangerous if they were not properly made; but some such arrangement as had been described prevented the danger, and that it would prevent priming he supposed was proved by practical experience. He had seen boilers, properly proportioned to their work—not double-flue, but single-flue boilers—which in the early days when the mode now described of carrying off the steam was introduced, by having a pipe inside the boiler perforated with holes along the top, primed fearfully from want of a steam dome, and could not by any means be kept up to ordinary work. One case he remembered where every means had been tried to prevent the priming, and the only remedy was to put on a steam dome; and from that day the boiler never gave any trouble in priming. The water used was ordinary water, not soft, and was the same both before and after the dome was put on. The same thing applied to the vertical boilers that had been spoken of, which were no doubt very excellent producers of steam; they went into a small space, and possessed the other advantages that had been already described; but they were liable to prime. The area of the water surface through which all the steam had to pass up was so small that the priming in this case was very serious indeed. If the steam was being carried off rapidly, as would be done by steam hammers working quick, it was astonishing what a serious nuisance priming was with narrow vertical boilers. The explanation he gave of it was that every particle of water was highly charged with steam by its temperature being so much above the boiling point of 212° on account of the boiler pressure, and as soon as this pressure was reduced by the steam being drawn off rapidly, all the molecules of steam in the water throughout the boiler made an effort to escape; but the sectional area of the boiler being so small, and the depth of water so great through which the steam must pass, it could not escape fast enough from the water; but the elastic force of the steam overcoming the gravity of the water forced it forward, and the whole body of the water was lifted to the top of the boiler, and thus produced priming; that was one of the things which militated

against vertical boilers. In the horizontal boilers the water surface was so large and the depth of water so small that the steam rose gradually, and with proper steam domes such boilers seemed to him to be under the best possible conditions to prevent priming. When a vertical boiler was priming, which it often did for hours together, the glass water-gauge was useless; he was sure that any one who had seen a vertical boiler priming would imagine from the glass gauge that the boiler was full of water. The fact was that the water was at the top of the boiler, instead of being where it should be, and the glass gauge was thus of no value at all; indeed gauge-cocks were then of no use—a most dangerous condition of things. As regarded priming therefore he thought the vertical boiler stood no comparison with the horizontal boiler.

Mr. L. OLRICK thought the last speaker must have been unfortunate with vertical boilers. Having himself had a tolerable experience of vertical boilers, of which he had made about a thousand, he had never had a single instance such as had been complained of, in which neither the water gauge nor the gauge-cocks were of any use. In a vertical boiler there was often a larger steam room than in a horizontal boiler without a dome; and that might account for it. In the vertical boilers which were stated to have primed so badly he thought the water must have been excessively soft. If water were taken from peat, no form of boiler could avoid priming; the best remedy was to put lime into the water, which would do away with priming.

Mr. J. ROBINSON was glad to hear of Mr. Head having had nineteen vertical boilers working successfully for a good many years, as in a place like Manchester the cost of land for setting up boilers was heavy. His own experience however of vertical boilers in Manchester was anything but satisfactory. These were like those used by Mr. Head, with a central uptake passing up through the middle of the cylindrical boiler, and taking heat from iron furnaces; and the result had been that a considerable amount of flame had passed up the uptake, and when the steam was taken

off it rushed from the water with such violence that it was really, as a previous speaker had said, very difficult to find where the water level was, and the amount of priming also was great; so that there had to be a considerable allowance between the proper position of water and the position at which it might appear to be, to avoid the danger of explosion from the water level getting too low.

In addition to this there was another danger which seemed to him to be inevitable in vertical boilers. Whatever Mr. Head might have said about taking out the heat passing up an uptake of that kind before it reached the steam space, he might state that in all vertical boilers he had himself seen that heat had not been so taken out, and a considerable amount of heat and sometimes a very red flame had passed up not only through the steam space of the boiler but out and beyond it. It seemed that had been feared in the boilers used by Mr. Head, for the wrought-iron chimney to take away the products of combustion was stated to be lined with brick—a very natural and proper precaution. In the neighbourhood of Manchester, not many years ago, a vertical boiler of that kind, but as far as he remembered without any cross-tubes to absorb the heat, actually did explode, from the fact he believed of the superheating of the steam; for the steam rising so far above the surface of the water was not able to saturate itself, because the distance from the surface of the water in a boiler of small diameter prevented the saturation from going on sufficiently rapidly, and the result he believed was a large increase of pressure of the steam by becoming superheated, and an explosion took place. Not only at the works where that accident took place but at his own works also the vertical boilers had since been taken down and laid horizontally, notwithstanding the enormous expense of doing it and the disadvantages connected with horizontal boilers.

Mr. HEAD observed in explanation, with regard to the question of the priming of vertical boilers, that there were of course vertical boilers of various types, and he admitted that it required care in the designing of the proportions to get an effective one. With the nineteen vertical boilers to which he had referred he had

never been troubled with any priming whatever. He attributed it partly to the fact that there was a considerable amount of steam pipe in connection with them, a number of boilers supplying steam into the same pipes—which thus acted as a sort of reservoir—and a number of engines taking the steam out; in that way the steam was drawn from each boiler in a very equable way, and there was no priming. On the contrary, with small vertical boilers which were also multitubular, such as were put on "coffee-pot" locomotives, he had known trouble to arise from priming, because the steam room was there often too limited.

With regard to the uptake going through the steam, he knew there were circumstances in which it might be dangerous, and that, where the design had been faulty, explosions had occurred. One of the vertical boilers of the make he had described with internal firebox had been at work at least two years and without any trouble. It must be borne in mind that the uptake was intersected in two directions by the cross tubes, which were also made somewhat stronger in the steam space than the lower cross tubes, to allow for possible corrosion; in his case he could not conceive that there was any danger of collapse. He had tried the heat when the boiler was first set to work, and had satisfied himself that there was no heat in the uptake capable of doing damage; but if he had found that the sting was not taken out of the heat at that height, it would have been a small matter to make the boiler a little higher, putting in more lengths of flue-piece with the cross tubes. With regard to the lining of the chimney above the boiler with brick, that was done simply to prevent the cold wind as it blew on the sides of the chimney from destroying the draught; there was no brick lining where the uptake passed through the steam; the bricks were simply above the boiler to keep up the heat of the chimney.

Mr. J. I. THORNYCROFT, in reference to the comparison made between the Lancashire boiler and the upright boiler, drew attention to the fact that in the Lancashire boiler a very great part of the structure was available for heating surface; of the outer shell about two-thirds of the surface was available for heating surface, whereas

in a vertical boiler, as submitted, the outer shell was he supposed much greater in proportion, and was not available as heating surface. He had no doubt that successful vertical boilers might be made, but one thing that militated against them was that in a vertical boiler the hot gases had a tendency to ascend faster than the cooler ones, and it thus happened that some parts of the products of combustion might remain in the boiler a considerable time, while the recently consumed gases might pass rapidly to the chimney; these were difficulties to be got over. With regard to priming, he thought the small surface of water in a vertical boiler was much against getting dry steam.

Mr. A. PAGET observed that in the list of boiler fittings described in the paper no mention had been made of a fusible plug; probably the author's reason would be that, while he thought it would do no harm, it really did no good, and this he knew was a general feeling; but he also noticed that one Manchester company undertook to insure boilers at a less premium if they were provided with a certain fusible plug. The author of the paper, with his large experience, ought to know the value of a fusible plug; but here was a company which also ought to have some knowledge of the subject, that offered to insure boilers at a less premium if this particular plug was put in, and he should like to ask whether the author thought the plug to be of value.

It was evident from the remarks of many speakers who knew so much about riveting and plates, that with all the present experience and experiments it was not yet known how to make the best riveted joints; and he suggested that it was very desirable that this should be known, and that it was an important point for the Institution of Mechanical Engineers to ascertain, for the benefit not only of the members but of the world at large, professional and unprofessional. It had been so clearly brought out that engineers did not yet know what was the best riveted joint—there being so much difference of opinion on the point—that he would suggest that the Institution should endeavour to do what in regard to screw threads one man had done years ago, and that they should try to

settle what really were the best proportions for a riveted joint. This would be an expensive and laborious undertaking, and one that no private person would like to undertake, but it might be undertaken by the Institution with great advantage. He ventured to hope that one of the many valuable outcrops from this excellent paper might be that the Council would consider whether, as some portion of the scientific investigation to be undertaken by the Institution, it could ascertain and settle what were the safest and best proportions for riveted joints.

Mr. J. PLATT remarked that it would be interesting to know how the author had brought about the extensive rents in the fractured specimens of boiler plates exhibited,—how the pressure had been sustained after leakage commenced. He had himself been quite struck to see the immense power required for it.

With regard to the question of punching versus drilling, he rather thought that very bad punching had been taken for comparison against very good drilling. It was some years since punching had been left off by Mr. Adamson, and at that time the process was not carried out in the scientific manner of the present day. It was now done in a very careful manner, the most skilled workmen were employed, the punches were made to a standard gauge, and the dies drilled out to another gauge, and the work was done by men who were so expert that he had little doubt they would punch a plate with not more than 1-32nd inch difference in pitch, or even less than that. However there was no doubt that a drilled hole must be more mathematically correct than a punched one; but it was a great question whether there was so much advantage in it as would justify going to the extra expense; as a boiler maker he only wished this might be the case. There was a difficulty in getting a sufficient price to make a decent job with punching; and as to drilling, the extra cost was out of the question in a great many cases.

With regard to cast-iron mouthpieces, something had been said about bad workmanship having perhaps been partly the cause of the failure of the fractured specimens exhibited. At his own works

the practice was to rivet the cast-iron mountings upon the boilers by a hydraulic machine, which could be done perfectly the same as the rest of the boiler work; it made a very good job, and avoided crystallising the iron by the hammer.

Mr. T. B. HALL considered the flanged seam was an admirable form of joint for boiler flues, well able to withstand the external pressure; but he should like to ask how a flue made with those flanged joints could be repaired without taking the end plate of the boiler out. It seemed to him that this form of flue was a great disadvantage in case of repair.

Mr. A. BOWER observed that the Board of Trade rule for calculating the strength of a boiler flue gave no limit as to the length of the flue, and would, as the President suggested, be evidently reduced to an absurdity by supposing the length to be indefinitely increased. Other rules of the Board were equally defective, and he might mention the rule which required an inferior factor of safety to be employed in cases where the boilers had not been specially open to inspection by the Board during construction; what there could be in their inspection to make iron stronger than it would be under other circumstances, he was at a loss to find out. He had listened with great pleasure to the paper that had been read, for which the author deserved great credit. In the style of boiler described he did not think any credit at all had been claimed for originality; it had been brought forward simply to show how an institution like the Manchester Steam Users' Association could by self-government and self-organisation bring about a good type of manufacture far better than by any government supervision. As a marine engineer he felt strongly that they were all indebted to the author of the paper, who had said simply that such a boiler would bear with safety a certain working pressure, not having to consider, as in marine work, whether it would please the Board of Trade. If land boilers ever came under the control of the Board of Trade, it was not likely that boilers of the kind described in the paper would be passed for such high pressures as they were now

satisfactorily worked at. Marine boilers now being made at his firm's works, 14 ft. diameter with shell plates $1\frac{1}{4}$ in. thick, would only be allowed to carry the steam pressure at which these Lancashire boilers of 7 ft. diameter and 7-16ths in. thickness were satisfactorily working; for such pressures these large boilers would be approved by the Manchester Steam Users' Association if made of plates $\frac{7}{8}$ in. thick, yet it was now compulsory to put plates of $1\frac{1}{4}$ in. thickness. Nothing would give him greater pleasure than to see the suggestion carried out, that this Institution should take in hand the establishing of what would be a well-made and well-proportioned riveted joint; and he would ask, if this were done, that the investigation should go far beyond the present type of Lancashire boiler, because it was seldom that such boilers went further than $\frac{1}{2}$ in. plates, and now in marine boilers plates were being riveted of $1\frac{1}{4}$ in. and even $1\frac{5}{16}$ in. thickness, and it was even contemplated that $1\frac{3}{8}$ in. might be required.

With reference to the difference between punching and drilling the rivet holes, he scarcely thought there was any maker of boilers who would venture to punch a joint with $1\frac{1}{4}$ in. plates; the difference in diameter between one side of the hole and the other would be so great that he did not think a good job could be made of it. In fact boilers of that type he felt were more the work of mechanics than boiler-makers. At his firm's works all the edges of the plates were planed and all the rivet holes drilled, and it was necessary to give such attention to the joints that the experiments suggested would be invaluable. Although it had been said the fractured specimens exhibited showed that the boiler from which they were obtained was not well proportioned, he considered every failure of a boiler in testing was of great advantage so far as gaining experience went; and these specimens, all fractured along a riveted joint, showed with certainty where the weak points were, and taught a far better lesson than if the boiler had been found to break sometimes in one place and sometimes in another.

Mr. J. ROBINSON enquired whether the $1\frac{1}{4}$ in. plates for marine boilers were bent cold; if so he should suspect the strength of the plates was greatly reduced in the operation.

Mr. BOWER replied that his firm never attempted to bend the plates without warming them, as very great risk would otherwise be incurred, and an element of danger would be introduced.

Mr. C. E. AMOS mentioned that with regard to priming he had himself experienced difficulties, and in one or two instances had got over them by the plan of fixing within the boiler, beneath the hole through which the steam rushed into the steam pipe, a piece of boiler plate as large as could be got in through the manhole; that piece of plate was jagged all round as rough as it could be made, with as sharp jags as possible. This plate was fixed at a short distance from the upper boiler plate, and the consequence was that, the steam rising all round the plate, the jagged edges of the plate cut through the stream of water that rushed up with the steam, and enabled the steam to escape into the steam pipe without carrying the water with it. It was a simple plan and very little cost.

Mr. FLETCHER said it had been suggested in the discussion that it would have been well if the paper had taken a somewhat wider range, and had entered upon a comparison between the Lancashire and other boilers. That would certainly have been a matter of interest, but the subject of the paper had been strictly limited; it only took up what was comparatively a narrow ground, the object being to meet certain practical difficulties that were met with in the use of Lancashire boilers, by giving an account of the construction, equipment, and setting found to give the most satisfactory results of those under the inspection of the Manchester Steam Users' Association. This boiler had become a general favourite for mill purposes, with certain variations. Some of the reasons for this were—it had a large water area from which steam could readily escape; it had steadiness in supply of steam; there was a large quantity of water forming a reservoir of steam power, so that such constant firing and feeding with water were not required as in the case of a boiler that contained much less water.

The Lancashire boiler laboured under the disadvantage of not being as portable as a sectional boiler or a water-tube boiler: that

must be granted; but the water-tube boilers had not fulfilled their promise of safety, as proved by the unfortunate experience of recent months; and where a boiler required such constant feeding with water and coal, that was of course a disadvantage. The Lancashire boiler had another disadvantage: it occupied a great deal of floor room; and it was generally found, as already stated, that, in drawing near the centre of large towns where rents were high, the boilers must be placed on end; but where rents were low, space could be afforded for laying the boilers horizontally. The true object of the paper had been to stimulate steam users to adopt a better style of boiler, and to stimulate boiler makers to keep pace with the higher style of construction, so as to convert a boiler into a piece of engine work.

He was sorry he could not agree with the statements that had been made in favour of vertical boilers; he thought them very dangerous, as he had had to investigate several explosions arising from boilers of that class, some of which had been attended with most dangerous consequences. The vertical boiler when it gave way shot up to a great height, and came down of course with considerable velocity, doing great harm. Where there was a long vertical heating surface, as in the uptake tube of a vertical boiler, steam was generated on the vertical surface, and in rising took the place where the water should be; the tube became coated and enveloped with an atmosphere of steam, the water was kept from contact with the plate, and the metal therefore became overheated, in consequence of which the tube worked out of shape and collapsed. These boilers had therefore come to be generally condemned, at all events that was very much the view held in Manchester, but he should be glad if these difficulties were overcome elsewhere.

Remarks had been made about longitudinal bolt stays. These as stated in the paper had been removed in the experiments upon the boiler described; and the photographs taken during the experiments showed that under the severe tests applied, the ends stood without any distress, and the tubes also; the rents took place in the longitudinal seams. That occurred over and over again, and he

thought must show that the ends did not want the help of longitudinal stays. Even in a plain cylindrical boiler the strain at the transverse seams and rivets was only half of that at the longitudinal seams; in the Lancashire boiler it was less, because not only was the area of the end plates, that was exposed to the steam pressure, diminished by the insertion of the tubes, but at the same time the longitudinal strength of the boiler was increased by introducing two very strong stays in the shape of these tubes themselves. The strain on the transverse seams in the Lancashire boiler was therefore much less than on the longitudinal seams, and thus the transverse seams had very much less to do. The longitudinal bolt stays seemed to him to have almost a sinecure; they should at all events, if put in at all, be put in perfectly slack, so as to lie idle until a transverse rupture occurred, when they could come to the rescue.

The riveting of the longitudinal seams in the experimental boiler had been found fault with by Mr. Adamson, who thought that a higher result could yet be obtained. He was very glad to hear him say so, and should be sorry to think that an ultimatum had been arrived at. The best form of riveted joint was an important question; the experiments in connection with the paper had already done good service he considered by showing that with punched joints a boiler of the thickness and size described could be depended on up to as much as 300 lb. pressure per sq. in. Such boilers as this were guaranteed to 75 lb. working pressure per sq. in., and this was based on the calculation that the bursting strain was 300 lb. and that a factor of safety of 4 was sufficient; he was glad therefore to have the corroboration of these tests showing that the calculation with regard to the bursting strain was correct, one of the seam rents exhibited having been burst at a pressure of 300 lb. and another at 310 lb., while one of the cast-iron mountings had been burst at 295 lb. In conducting such experiments difficulty arose if it was attempted to do too much at one time; he had been recommended to try a wider pitch of rivets than that in the specimens shown, and had commenced trying different widths at the same time; but he found this was a mistake, and that it was

impracticable to test several different things at the same time. Having been disappointed in trying to do too much at first, he had resolved to adhere to one thing and carry it out fully, and had accordingly made all the tests with punched holes for the riveted joints and all of the same pitch. Another set of tests might be made with drilled holes, and he should be glad to see them carried out.

In adopting 4 as the factor of safety for the boiler in working, and he was glad that exception had not been taken to this factor, the principle had been to reckon the strength of the boiler in strips of 1 in. or 2 in. width, and to take each strip on its own merits; and the factor of safety of 4 was applied to the weakest strip that could be found in the boiler. No credit was taken for crossing joints; but wherever a hole was made, the opening was atoned for by putting on a strong mouthpiece. On the old system of allowing a factor of safety of 6, a good deal of looseness had been allowed; plates were cut out, and manholes were left unguarded, because it was thought that with so large a margin of safety carefulness in those respects was not required; at the same time credit was taken for crossing joints. So that if the actual strength of the boiler as now made were calculated with a factor of safety of 4, it would be found that there was not much difference between the result so obtained and that arrived at by the old system of calculation where a factor of safety of 6 was presumed upon.

Attention had been called to the steam dome, and a plan for strengthening it had been shown by Mr. Cowper. No doubt the flat plate across the base of the dome was just what was wanted—something to tie the sides of the boiler together; at the same time he doubted if this fully atoned for the weakening effect of the dome. As to flanging the shell of the dome itself for attaching it to the boiler, he had had occasion only last summer to investigate for the Board of Trade two explosions that had occurred with well-made marine boilers, having flanged domes secured with double riveting; in both cases the dome was blown off, the fracture running along the line of rivet holes in the flange. There was evidently a very weakening effect in flanging the iron; it would be better he

thought to put a strong angle-iron there, because a greater amount of metal could thereby be introduced at the joint. In the very act of flanging, the metal was sometimes weakened; and if such a dome with a flanged joint were severely tested with hydraulic pressure, he was afraid the result would be that the dome would shoot upwards by the failure of the flanged joint.

Reference having been made to insuring boilers, he wished to say that he had nothing to do with the insurance of boilers. The inspection of boilers was one thing, insurance was another; the question was an interesting and a long one, but could not then be entered upon. He hoped all would try to do what they could to stimulate the use of first-class boilers, got up with the same care and finish as engines.

The PRESIDENT thought this had been one of the best discussions at which he had ever been present. He hoped that Mr. Fletcher would continue his investigations and give the further results on a future occasion. There was one subject that affected the construction of boilers in several respects, that had not yet been touched upon—that was, the self-acting feed of furnaces. He believed it was a matter that should be studied in connection with the construction of boilers, and that it would in many respects modify the construction of them. He thought the time was coming when the self-acting feed would be much more employed than at present.

He moved a vote of thanks to Mr. Fletcher for his paper, which was passed.

The Meeting was then adjourned to the following day.

The Adjourned Meeting of the Members was held at the Institution of Civil Engineers, London, on Thursday, 4th May 1876; THOMAS HAWKSLEY, Esq., President, in the Chair.

The following paper was read:—

DESCRIPTION OF THE OGI PAPER MILL, JAPAN.

By Mr. WILLIAM ANDERSON, of London.

The Ogi Paper Mill is situated in the neighbourhood of Yeddo, and belongs to a Japanese company. It has been designed for the manufacture of paper from rags or from prepared fibres, and produces all the kinds of engine sized paper that are used for printing, packing, wall papering, &c., and also the lower qualities of writing paper. A general plan of the mill is shown in Fig. 1, Plate 11, and longitudinal and transverse sections in Figs. 2 and 3, Plate 12. The Ogi mill is one of recent construction, having been erected by the author's firm in 1874, and will serve as an illustration of a complete paper-making establishment with modern machinery.

The process of manufacture of paper is divided into two portions—first the preparation of the material, and second the making of the paper. The first portion, comprising the preparation of the rags to form the pulp from which the paper is subsequently manufactured, consists of the following series of processes—sorting, cutting, dusting, boiling, washing, bleaching, beating, and colouring.

Sorting.—The rags are stored in a warehouse detached from the mill and are first carefully picked over in the sorting room, to cut out all silk or woollen material, buttons, hooks and eyes, &c., and separate them into different qualities. This is generally done by women, at the separate small tables shown in Fig. 1, each 4 ft. by 2 ft., which are made with one half of the top of coarse wire netting three meshes to the inch, out of the middle of which projects a knife blade against which the rags are cut, the dust and fluff falling through the netting. The number of sorters required depends entirely upon the quality of the rags used and of the paper made; in the Ogi factory twenty-seven tables are provided.

Cutting.—The rags are then cut up into small pieces by a Cutting Machine. In many paper mills this is done by hand by the sorters. The cutter, shown in the plan, Fig. 1, is of Bryan Donkin and Co.'s make, and consists of a flat iron plate upon which a cross knife and three longitudinal knives descend, being so adjusted as just to touch and press upon the plate. The rags are fed on to the plate by a travelling leather band about 9 in. wide, which has an intermittent motion, and works over the bottom of a trough into which the rags to be operated upon are laid; the knives have a stroke of 6 in. and make sixty cuts per min., dividing the rags into cubes of about 3 in. on the side. At first sight it would seem that the knives, actually cutting down upon an iron plate, would not long retain their edges; but experience has shown that if the machine is carefully adjusted, which is easily done, the knives are not blunted by the iron plate, but by the material they cut. In cutting the worst materials, the knives require re-sharpening every two or three days. Besides the saving of labour effected by the cutting machines, they have the advantage of dividing the rags sharply, and without shreding them, into regular sizes; which is important, because in a manufacture where a regular result is to be obtained—such as uniformity of texture, strength or colour—every stage of the manufacture should be also as regular as possible. The other materials—old rope, hemp, flax, and other prepared fibres—that are used for paper making, are treated in the same manner as rags.

Duster.—From the cutting machine the rags are taken to the Duster, which is shown in Fig. 1, and is a cylinder of open woodwork, lined internally with wire net, three meshes per in., and having a number of pointed iron spikes, 6 in. long, projecting inwards. The cylinder is 4 ft. 6 in. diameter and 15 ft. long, placed at an inclination of 1 in 16, and revolving five times per min. upon friction rollers on which rest the angle-iron rings that form the ends of the cylinder. The rags are fed in at the upper open end of the cylinder, and after being well tossed about by the spikes tumble out on the floor at the lower end, the dust and dirt falling through the wire sides. In some mills the rags are torn to pieces by a "devil" or rough carding engine, but it is generally allowed

that there is a considerable loss of fibre from such violent treatment. For very low qualities of rags, washing machines of a similar construction to the duster, but working in water, are used, and a great deal of dirt is thus got rid of before the next process of boiling. The dusted rags are next weighed into sacks or baskets and carried up on to the stage over the boilers.

Boiling.—This is done in a pair of revolving boilers shown in Figs. 1 and 3, and enlarged in Figs. 5 and 6, Plate 13. These boilers are of wrought iron with domed ends, and are 6 ft. diameter and 10 ft. 6 in. high, capable of containing a ton of rags in each, and standing a working pressure of 60 lb. per in. There is a manhole at one end of each, with the wrought-iron lid fixed by tee-headed bolts, so arranged that they can be readily taken out after slackening the nuts a turn or two; the joint is made either with dry gasket or with "half-stuff." The other end of each boiler is fitted with a perforated false bottom E, Fig. 5, covering about two-thirds of the rounded end. Each boiler is carried upon two hollow trunnions F F, through one of which steam is admitted by a pipe that discharges under the false bottom, and the other admits either water or alkali solution in all positions of the boiler whether standing or revolving; a drain cock is fixed in the end under the false bottom. The boiler revolves in massive cast-iron A frames, to which all the gearing is fastened, so that the whole is completely self-contained; it is made to revolve upon the trunnions once in 10 min. by means of a wormwheel and screw driven by bevil wheels actuated by fast and loose belt pulleys. The boiler is charged with rags through the manhole from a hopper above, and after being filled about half full with water through the trunnion, steam is turned on, and the manhole lid fastened down, the air escaping at a cock in the lid. As soon as the water boils, which is ascertained by steam issuing from the air-cock, the boiler is set in motion and kept revolving until the rags are sufficiently cooked. The time of boiling varies very much with the quality and kind of material, but generally lasts 3 to 5 hours. As soon as the cooking is done, the boiler is stopped with the false bottom downwards, the spent liquor

is run off by the drain cock, and as soon as all the steam has escaped the manhole lid is removed, the manhole end of the boiler turned down, and the rags allowed to tumble out on the flagged floor. A few turns of the boiler, aided by a rake, suffice to empty it, and the boiled rags are then placed in bins shown in Fig. 1, ready for the next process. Sometimes clear water is introduced after the spent liquor is out, and before the manhole is opened, and a few turns given to partially wash the rags from the alkaline solution.

There are many varieties of rag boilers—some fixed and open at top, boiling at atmospheric pressure; others spherical, and others cylindrical revolving about their long axis,—these generally use high-pressure steam. There is not much difference in the efficiency of the high-pressure revolving boilers, but the author prefers the form described, as it takes less room, and tumbles the rags about well without the aid of shelves or spikes. In some cases a perforated iron diaphragm is put in across the boiler so as to let the rags be drained and immersed alternately, a manhole being then provided at each end. The air-cock is made, in some cases, to open each time it reaches the highest position, so as to let out any air that may have collected.

Alkali is added to the water during the process, in different forms and proportions according to the quality of the material and the paper to be produced. With rags, where the only object is to dissolve all fatty and greasy matter and get rid of as much dye as possible, the quantity used varies from a few ounces of lime or soda-ash to 56 lb. of caustic soda per ton of rags; while with raw fibres, such as straw and esparto, 4 cwt. or even 5 cwt. of soda-ash is used per ton. When the smaller proportion of alkali is sufficient, it is put direct into the boiler in the solid form or simply dissolved first in a bucket; but when the larger proportion is required, it is necessary to have suitable alkali-mixing apparatus. In the Ogi mill it was thought advisable to prepare for the use of raw fibre, many varieties of which, suitable for paper making, being abundant in Japan; and room was therefore left for a fibre-boiler, and an Alkali-mixing apparatus was supplied. This is shown in Fig. 1, and enlarged

in Figs. 7 and 8, Plate 14, and consists of a sheet-iron dissolving vessel G, 7 ft. 3 in. diameter and 3 ft. 3 in. depth, furnished with a revolving agitator working in a horizontal plane near the bottom at 11 rev. per min., and capable of being easily stopped and started. The vessel is fitted with a perforated steam pipe H running round the bottom, with a wash-out plug and pipe for letting out the spent or insoluble materials, and with a descending overflow pipe I arranged to slide through a stuffing-box in the bottom by means of a handwheel and screw. Immediately under the dissolving vessel is a wrought-iron store tank K, 10 ft. by 6 ft. and 4 ft. deep, fitted with a wash-out plug and pipe, and with a 2 in. liquor main to the rag boilers, governed by a stop-cock, the handle of which L is carried up to the stage above the dissolving vessel. The store tank rests on two walls, which include between them a brick spent-ash and lime tank M, into which the spent materials, previously mixed with a little water, are let down and allowed to settle. The clear weak liquor, which separates here by subsidence, is pumped up again into the dissolving vessel by means of a small plunger pump N driven by fast and loose pulleys; the suction pipe, terminating in a short length of flexible pipe, is let down into the clear liquor as far as necessary to ensure its coming off tolerably clear.

Caustic soda (Na H O new notation) solution is made by putting into the dissolving vessel the lumps broken out of the iron drums in which it comes from the alkali works, turning on the steam to boil the water, and starting the agitator, and a solution of given strength is obtained. When soda-ash is used, that is impure carbonate of soda ($Na_2O\ CO_2$), it is dissolved in the same way, after which freshly burned lime well screened is added to the solution, till the carbonic acid of the soda has all combined with the lime, forming a precipitate of chalk and excess of lime, which, after a few hours' standing, collects at the bottom of the vessel, and the clear solution of caustic soda, is then carefully decanted by means of the sliding overflow pipe into the store tank beneath. Fresh water is then added to the dissolving vessel, it is boiled up and mixed with the sediment by means of the agitator, allowed to subside, and then decanted into the store tank, the solution in

which is thereby weakened a little. Water is again let into the dissolving vessel and the sediment roused up and let down at once into the lowest brick tank where it again subsides, and the clear liquor is pumped up into the dissolving vessel to be used instead of fresh water with the next charge of alkali. Alkalies are generally sold according to the percentage of caustic soda they contain, so that the paper-maker knows the value of each lot of ash or caustic he receives; and the proportion of soda-ash used is regulated by the percentage of caustic soda it contains, so as to ensure a constant weight of caustic soda to each gallon of solution supplied to the boilers, and the quantity of solution is gauged by running out a given number of inches from the store tank into the boilers, and by that means the regularity and precision in the boiling process are secured that are so necessary in the manufacture of paper. The strength of solutions is also roughly ascertained by observing the specific gravity at a fixed temperature by means of a hydrometer. The proportion of lime used is about 90 per cent. of the weight of soda-ash at a strength of 50 per cent. of caustic soda. In rag mills the quantity of alkali used is so small that it does not pay to recover it from the liquor let out of the rag boilers; but when raw fibres are dealt with, the spent liquor is now very generally first concentrated and then incinerated, and an impure carbonate of soda obtained, which has to be prepared for use exactly like fresh soda-ash.

Washing.—The next machines are the Washers, by which the rags are opened out or disintegrated, so that they may be thoroughly washed; the position of the washers is on an upper floor, as shown in Figs. 2 and 4, Plate 12. The boiled rags are packed into a wagon in sufficient quantity to charge a washer, and raised from the lower floor by means of a hydraulic lift, shown at A in the general plan, Fig. 1, worked by the pressure in the water mains; and the wagon is then run behind the washers, into any of which its contents can be readily emptied. The wagon travels on a light tramway of flat iron rails furnished with turntables where required. There are five washers, shown enlarged in Figs. 9 and 10, Plate 15; each consisting

of an oval cast-iron tank, 10 ft. 9 in. length, 5 ft. 4 in. width, and 2 ft. 1 in. depth, fitted with a horizontal roll H, 2 ft. 2 in. diameter and 2 ft. 4 in. length, revolving 160 times per min. This roll contains seventeen clumps of bars or "knives" of two in a clump, that run in very close proximity to a plate I below, that carries seventeen knives 5-16 in. thick, bolted close together, and set at an angle to the roller-knives, so that they have a scissors action upon the rags that pass between them. These lower knives are placed in an iron box sliding into a recess immediately under the roll; and the bottom of the tank has inclined surfaces leading up to and falling away from the knife roll. The adjustment of the rolls to the stationary knives is effected by two side levers or "lighters" K K, one on each side, that carry the bearings of the roll shaft. One end of each lever works on a pivot secured to the outside of the tank, and the other end is supported by an adjusting screw, the nut of one of which is formed into a handwheel, by which the height of the roll is easily adjusted whilst at work. The brasses in which the shafts run have a considerable range of adjustment in the line of the levers, and are kept in their places by horizontal set-screws. The object of this arrangement is to give the means of adjusting the roll to the best position with reference to the concave in which it works, and to compensate for the wear of the knives. Some makers connect the adjusting screws of the pair of lighters by a cross shaft and gearing, so as to make the rolls rise and fall without angling the shaft, but the motion is so small that adjusting one side only appears to be practically sufficient; at any rate paper-makers do not seem to set much store by the more complete arrangement. The roll is at one side of the tank, which has a longitudinal partition in the centre, and the rotation of the roll causes the stuff to circulate round the tank.

A large sand strainer L is fixed in the bottom of the tank, and a smaller one M in the incline leading up to the roll; these are cast-iron gratings with about 3-16 in. openings, through which sand and other heavy matters gradually find their way into recesses, from which they are removed from time to time; but the rags or fibres, being of nearly the same specific gravity as the water, have no tendency to

fall through. The gratings are lifted from time to time when the washers are empty, and the sediment removed; sometimes this is done by flushing when the washers are running full, but that is a bad practice, because it leads to a waste of fibre. A stream of clear water is constantly being run in at one end of the washer and lifted out again at the other end, by means of a revolving "drum-washer" or kind of scoop wheel N, 2 ft. diameter and 2 ft. length, shown in section in Fig. 14, having four copper scoops enclosed in a cylinder of fine brass wire gauze of 60 meshes to the inch. The scoops deliver the water at the centre into troughs by which it is conveyed away. The drum-washer is driven from the roll shaft, and works in bearings capable of being raised or lowered by means of a pair of racks and pinions, the latter keyed on a shaft common to both, and actuated by a handwheel. The periphery of the drum-washer moves faster than the circulating stuff, and thus continually disengages itself from the stuff, which would otherwise cling to the wire gauze and soon stop its action. Although fibres will pass through an exceedingly fine slit, they do not get through small square holes, as in the wire gauze, and hence the drum-washer removes very little, if any, fibre.

Besides the means above described for removing the washings, advantage is taken of the water thrown up by the rapid rotation of the knife roll, which is caught by a wooden hood O, furnished at each end with frames S S covered by fine wire gauze called "tap-boards," which intercept the fibre, but allow the water to pass through and escape into spouts fitted for the purpose. When it is desired to stop the action of the tap-boards, shutters are interposed between them and the rolls, shown by the dotted lines P P in Fig. 9. The water separated by the drum-washer and tap-boards falls into an open trough placed beside the washer on the floor, and thence into a waste-water drain. The open trough is used to facilitate the inspection of the water, so that any escape of fibre may be readily detected. Each washer is furnished with two 7 in. valves for letting out the stuff either into the shoot leading to the bleach house, or, when no bleaching is required, into the "beaters," which are for this purpose placed immediately under the washers. For washing

down and cleansing, a $3\frac{1}{2}$ in. waste-water valve and pipe is fitted. Clean water is furnished by a stand-pipe fitted with a cock and spreading-pipe, which distributes the water over the stuff just before it passes under the roll; a 1 in. cock with hose connection is also fitted to the stand-pipe for the purpose of washing down. Each washer has a working capacity of 80 cub. ft., and will hold about 200 lb. of dry material.

Bleaching.—After the rags have been opened out and thoroughly washed, the mass is technically termed "half-stuff," and is fit for bleaching. For this purpose it is let down into a wooden shoot, laid at an incline of $\frac{1}{4}$ in. per ft., by pulling up the 7 in. stuff-valves in the bottom of the washers, and allowed to flow into the Bleaching Tanks or "Poachers," which are shown in the general plan, Fig. 1, and enlarged in Figs. 15, 16, and 17, Plate 16; they are of cast-iron, similar in form to the washers, only much larger, being 18 ft. length, 9 ft. width, and 4 ft. depth, and each contains as much as about 7 washers or 560 cub. ft. The roll P is 5 ft. diameter and 4 ft. 3 in. width, revolving ten times per min., and it is fitted with paddles which keep the "half-stuff" in circulation. It is also fitted with a drum-washer R, 2 ft. 9 in. diameter by 3 ft. 9 in. length, by means of which the water is drained out of the half-stuff until this is as thick as it can be got to circulate. As soon as this occurs, and the poacher has as much half-stuff as it will hold, the drum-washer is raised clear of the stuff, and a certain quantity of bleaching powder solution is run in and mixed thoroughly with the stuff by the action of the paddles on the roll. The proportion of bleach added, and the time of mixing, vary very much with the quality of the rags or the paper to be produced; fine white rags, such as are used in making bank notes, do not require any bleach, while straw takes as much as 2 cwt. to the ton. The exposure to the light and air that is effected by the constant turning of the stuff is a powerful auxiliary in the bleaching operation. When the half-stuff has been sufficiently long in the poachers, it is let out by means of 7 in. valves into a wooden shoot, which is carried at an incline of 1 in 45 over ten masonry steeping chests, shown in Fig. 1, each of sufficient capacity to hold

the contents of a poacher. The bottoms of these chests are made to slope towards a central drain covered with perforated tiles, and furnished with an outlet cock by means of which the spent bleach may be drawn off. After standing some time in steep, the half-stuff is allowed to drain, and when dry enough is taken out of the steeping chests and heaped up in bins, which are also furnished with drains covered with perforated tiles, and it is allowed to gain additional colour by exposure to the atmosphere. The partially spent bleach is collected from all the tanks and bins into a masonry well under the poachers, and pumped up thence by a small plunger pump into the poachers, where it serves to displace some of the water let down with the half-stuff from the washers, and expends its feeble remaining bleaching powers on the fresh stuff.

The Bleach-mixing apparatus is shown in Figs. 1 and 2, and enlarged in Figs. 18 and 19, Plate 17, and consists of a cast-iron dissolving tank O, 6 ft. diameter and 4 ft. depth, fixed 4 ft. above the ground, and fitted with a revolving agitator. The bleaching powder ($CaO\ Cl_2O + CaCl_2\ 2CaO$) solution is prepared by filling the tank half full of clean water, and throwing in about 630 lbs. of powder; the agitator is then started and the tank filled up with water. After about three hours' mixing, the solution is left to stand twelve hours, and the clear liquor, which then indicates 11° of Twaddle's hydrometer, is pumped up into the store tanks P P, which are two cast-iron tanks 6 ft. 8 in. square and 3 ft. 4 in. depth, fixed on brick walls at a height of 18 ft. 6 in. from the ground. The clear liquor is pumped out from the dissolving tank by a small plunger pump R, with a $2\frac{1}{2}$ in. suction pipe inserted 15 in. above the bottom, and fitted with a short flexible hose, having a bib end S supported inside the tank by a gutta-percha cord and balance weight, to adjust the depth from which the liquor can be drawn off clear. The tank is then half filled again with water, and 525 lbs. of bleaching powder added, the agitator worked again for three hours and the tank filled up, and when thoroughly mixed allowed to settle eighteen hours; the resulting clear solution, which again indicates 11° of the hydrometer, is pumped up as before into the store tanks. The dissolving tank is again half filled with water,

the agitator worked for half an hour, and the whole contents are then discharged by an outlet valve into one of the two spent-bleach tanks T T under the store tanks. A clear liquor of 3° strength is there separated, which is pumped up into the store tanks, and thereby reduces the strength of solution in them to 8°, at which it is generally used; the actual proportion of bleaching powder in the solution is 1151 lb. in 1736 gall. of water, or 0·66 lb. per gall., and any given weight of bleaching powder can therefore be readily measured into the poachers by calculating the number of pounds corresponding to each inch depth of the store tanks. The spent powder, when drained of all the liquor, is dug out of the bins and thrown away. The strength at which bleach solutions are used varies as much as from 5° to 12° Twaddle; about 4 lb. of bleaching powder per cwt. of fine rags, and 6 lb. for coarse rags, is a common allowance. The powder is supplied in casks of 5 cwt. each, of different qualities according to the percentage of chlorine, the usual strength being 36 per cent.

The clear bleach-liquor is carried from the store tanks by 2 in. lead pipes fitted with lead valves U U, and discharging into the bleach gauge-tank C, Figs. 1 and 2, placed in the wall behind the poachers and at a height to command them. This tank is of cast-iron, 3 ft. 11 in. square and 3 ft. 7 in. depth; it is fitted with a 2 in. branch and hose for running the bleach into the poachers, and is used for measuring the quantity so run in. A $\frac{3}{4}$ in. lead pipe is carried from the bleach main to the beater stage, for the purpose of supplying a little bleach to the beaters when it is necessary to bring up the colour of the stuff.

Beaters.—The bleached half-stuff, after having been thoroughly drained in the bins and brought to a proper colour, is packed in wooden wagons of the proper capacity to charge one beater, and is run along a tramway to the hydraulic lift B that raises it to the Beaters, which stand directly below the washers, as shown in Figs. 11, 12, and 13, Plate 15. They are the same in form and dimensions as the washers before described, excepting that the clumps of blades in the roll T have three instead of two knives each,

and the bottom plate has twenty-four knives $\frac{1}{4}$ in. thick; also the sand strainers at the bottom and the drum-washers are omitted, and the hoods are supplied with only one tap-board instead of two. The beaters are driven rather faster than the washers, and run at 180 rev. per min. The office of the beaters is to reduce the half-stuff to the proper state for making the required quality of paper, and in doing this lies the main art of the paper-maker. The time necessary for beating a charge varies from two to nine hours, according to the nature of the fibre required in the paper, three to three and a half hours being the usual time. If the fibre is to be short and coarse, the roll is let quickly down on the plates and a rapid cutting action takes place; but if a long fine fibre is required, the roll is let down very steadily and with great care, so that the fibres of the material are, as it were, rubbed asunder and split longitudinally instead of being cut. The half-stuff when placed in the beaters is generally in a nearly neutral state, but if it is found to show traces of bleach, it is washed whilst being worked by means of the tap-board S, and a stream of clear water admitted from a 1 in. cock, branching from the same stand-posts that supply the washers. To hasten the killing of the bleach a solution of hyposulphite of soda ($Na_2 S_2 O_3$) is often used. It is also while the stuff is in the beaters that resin-size and colour are added, when required by the nature of the paper to be manufactured; and there too any adulterating materials, such as starch and china clay, are applied. The finished stuff is discharged by valves in the bottom of the beaters into either of two separate wood shoots, laid at a slope of $\frac{1}{4}$ in. per foot, which convey it to either of two stuff chests placed at one end of the machine room. The object of this double arrangement is to allow two different qualities or colours of stuff to be prepared at the same time in different beaters, ready for the supply of the paper-making machine when changed from one sort of paper to another, the white and the coloured stuff having to be conveyed separately in different shoots.

Size Making.—The preparation of the vegetable size is a very important process; the position of the apparatus for this purpose, and of the tubs for mixing the lime-water and colours, is shown in

the general plan, Fig. 1. The Size-making Apparatus consists of a cast-iron pot, 3 ft. 6 in. diameter and 3 ft. 3 in. depth, holding 170 gall., fitted with a 1 in. steam coil, and fixed high enough to command three covered store tanks of wood lined with lead, and fitted with covers to keep out dust and fragments of the materials used in the process. Lime-water is prepared in one of two pairs of wood tubs, by mixing one part of fresh slacked and screened lime with eight parts of cold water, and allowing the mixture to stand about eight hours, till a perfectly clear liquor separates, and can be drawn off by a cock placed at a proper height in the tub; 24 gall. of this lime-water is run into the iron mixing pot. To this is added 70 lb. of soda crystals ($Na_2O\ CO_2\ 10\ Aq$), and heated by means of the perforated coil of steam pipe until fully dissolved; then 168 lb. of powdered rosin is put in, and the boiling kept up with gentle stirring for seven hours, during which time 30 lb. of rice flour, and half-pint of neatsfoot oil are added. When the whole is thoroughly dissolved and blended, the pot is filled up with water, and the heating and stirring continued till a perfectly even light yellow fluid is obtained, which is then run into the store tanks for the supply of the beaters, to each charge of which about ten pints of size are used. If size is imperfectly made, it is apt to stain the paper and do a great deal of mischief. Colours for the most part are obtained ready for use, and are simply added by weight or measure to the beaters. Sulphuric acid is used in the washers, poachers, and beaters to discharge colour or neutralize alkali.

Paper-making Machine.—The stuff prepared as has been described is now ready to be made into sheets in the Paper-making Machine, shown in the general plan, Fig. 1, and an enlarged elevation and plan in Figs. 20 and 21, Plate 18. The actual conversion of the pulp into sheets of paper comprises the following series of processes—straining, knotting, paper-making, pressing, drying, glazing, cutting, sorting, polishing, and packing.

Strainer.—The two chests that receive the stuff from the beaters are shown in Figs. 20 and 21; they are 12 ft. diameter and

5 ft. 6 in. depth, and are fitted with revolving wood agitators, which are so arranged that at each revolution they cut through nearly the whole of the contents of the chests, thus keeping the stuff at a uniform density. They run at 7 rev. per min., and are driven overhead by bevil gearing from a cross shaft common to the two chests; special precautions being adopted to prevent dirt or grease getting into the stuff. The chests are raised 15 in. above the floor level for the convenience of leading out the 4 in. pipes which connect them to the stuff pump; the outlets of the pipes are guarded by fan regulators, working level with the bottom of the chests. The stuff is drawn out by a pump of the bellows type, having a 13 in. barrel covered by a raw hide diaphragm, and actuated by a crank of variable throw, working at 60 double strokes per min., the stroke being only from $1\frac{1}{2}$ to 2 in.; the valves are of the fish-mouthed kind made of india-rubber. The pump delivers into a small iron regulating cistern on the top of the rising main, which is also furnished with a large air vessel; and an overflow notch 12 in. wide near the top of the cistern discharges the surplus stuff back into either of the chests. The pump is adjusted in length of stroke so as always to raise a greater quantity than is consumed by the paper-making machine, into which the stuff flows from the regulating cistern through a V shaped opening that is closed by an inverted V shaped sluice, so that a uniformly square opening is always maintained, whatever may be the size to which it is adjusted. This sluice is actuated by a fine pitched screw and handwheel, and serves to regulate the flow of stuff on to the machine. The object of the above arrangement is to insure an absolutely uniform flow of the stuff, which is of special importance for obtaining uniformity in the continuous sheet of paper manufactured from it, by maintaining a uniform head for the flow from the cistern, whatever variation of level there may be in the contents of the chest. In order to reduce to a minimum the chance of sand or other hard matters getting into the machine, where they would do great mischief, the stuff in passing from the regulating cistern flows over a large strainer, consisting of a shallow wood tray, 13 ft. length and 3 ft. width and 9 in. depth, placed at a slight inclination, and fitted with a frame containing about fifty little

weirs, over which the stuff flows, depositing, in the eddies formed, any gritty matters or knots that may have escaped the sand strainers in the rag engines. This strainer is easily cleaned by raising the frame and flushing the tray when the machine is being washed down, and it is surprising what a large quantity of sand is caught in the upper part of this apparatus.

Knotters.—The stream of stuff in passing to the strainer is mixed with a large stream of water delivered from the back-water pump of the machine, and flows thence into two Knotters, by which a further separation takes place, not only of knots and impurities, but also of strings of matted fibre, or fibre not ground fine enough. These knotters are shown in Figs. 20 and 21, and enlarged in Figs. 22, 23, and 24, Plate 19. They are composed each of a set of three brass plates L, 1 in. thick, perforated with numerous very fine slits, the widths of which are designated by a series of letters and numbers, and vary with the class of paper to be made; the manufacture of these plates requires special machinery, and is confined to two or three makers. The perforated plates L form the bottom of a shallow brass box, 5 ft. 3 in. length, and 2 ft. 2 in. width, and 7 in. depth, below which is a diaphragm M, of $\frac{1}{2}$ in. india-rubber, fixed round the margin and connected by vertical rods N N to two levers worked by eccentrics below, the speed of which is regulated by driving cones to from 90 to 160 strokes per min., giving a stroke of 9-16th inch to the india-rubber diaphragm. The perforated plates are fitted into a rebate in the bottom of the brass frame, and this fits loosely into a cast-iron frame to which it is connected by ten bolts that draw it down upon the frame carrying the india-rubber diaphragm. The india-rubber is held up to its frame by a washer-frame and numerous bolts, and the middle part of the diaphragm is supported by a fixed wood cross-bearer O, to which it is securely held by a dished brass washer-plate screwed on above. Each half of the diaphragm is supported by a block of wood secured to the under side, and attached to the pair of connecting-rods N N by which motion is given to the diaphragm; these connecting-rods are actuated by eccentrics, which have a stroke of $\frac{3}{4}$ in. that

is reduced by levers to 9-16th in. motion of the diaphragm. A 5 in. discharge pipe passes down through the fixed centre cross-bearer, and is carried through the side of a distributing vat P, in which it turns up again, ending in a sliding bell-mouth R that is at a level of one or two inches lower than the knotter plates. The propelling power for the stream of stuff is the difference of level between the mouth of this pipe and the stuff in the knotters, which is made to cover the perforated plates about $\frac{1}{2}$ in. deep; and therefore by altering the level of the sliding bell-mouth the rate at which the knotter passes the stuff can be accurately regulated. The pumping action of the diaphragm has the same effect as the jarring motion in use in the common rapping knotters, but it has the advantage of being quite silent in its action, and therefore much more durable. Such fibres and impurities as cannot get through the slits are scraped off from time to time by the attendant, and these are worked up afterwards into inferior papers.

When coarse papers are being made the knotters are frequently not used at all, the stuff being run direct into the distributing vat P. This is a cast-iron trough, 7 ft. length, 2 ft. width, and 3 ft. depth, having a semi-cylindrical bottom, with a horizontal paddle or agitator S running close to it at one-tenth the speed of the knotters, from the shaft of which it is driven by a light belt. The stuff is discharged by an overflow lip 6 ft. wide, into the distributing box T of the shake-frame; a vertical partition in the trough compels all the stuff to pass under the agitator, and prevents the passage of any froth that may be caused by the knotters.

Shake-Frame.—The stuff has now reached the Shake-Frame on which the paper is made; a longitudinal section of this is shown in Fig. 25, Plate 20, and transverse sections in Figs. 26 and 27, Plate 21. The paper is made upon a travelling web A of fine wire gauze, about 60 meshes per in., forming a bed 8 ft. length and 6 ft. 6 in. width, upon which the stuff flows from the distributing box at the rear end, and the distribution of this stuff in a uniform thin layer is obtained by means of a transverse shake motion that

is given to the whole frame, carrying the wire web and connected apparatus. This frame consists of a pair of independent longitudinal cast-iron girders, carried at the rear end by a pair of vertical pillars B having ball-and-socket joints, and centred at the other end upon a pair of stationary ball-and-socket joints; a rapid transverse shake is given to the rear end by a horizontal connecting-rod from a bell-crank lever C, shown in Figs. 28 and 29, that moves the frame about 3-16th inch, at a speed of from 90 to 150 double strokes per min. This speed is adjusted by a pair of driving cones, on which the belt is traversed by means of a screw and handwheel. The ball-and-socket joints of the vertical pillars are made with spherical-headed screws, capable of being raised or lowered to the extent of 3 or 4 in., and the horizontal connecting-rod is also fitted with ball-and-socket joints; the object of this arrangement is to admit of the rear end of the shake-frame being raised or lowered to suit the quality of paper.

The wire web is an endless band stretched over a roller at each end, and kept tight by guide rollers below in sliding bearings, secured by pinching screws, one roller having its bearings adjusted by a screw movement for putting a greater strain on the wire than could be done by hand. At the rear end the wire web passes over a brass "breast-roll" D, 12 in. diameter, jacketed with felt, and it is supported throughout a length of 8 ft. by a series of forty-eight small rolls $1\frac{3}{4}$ in. diameter. The distributing box at the rear end is fitted with an india-rubber apron that laps over the wire web to prevent the escape of stuff, and the stream of stuff is enclosed at the sides by two "deckle-bands" E E, which are endless india-rubber bands, $1\frac{1}{2}$ in. wide, $1\frac{1}{4}$ in. thick, and 20 ft. length, stretched over flanged pulleys that are carried in brass frames which are threaded on two transverse bars, that have vertical screw adjustments upon pillars fixed in the side girders. Each deckle-band is tightened by passing over a pair of pulleys carried on the two arms of a bell-crank, which can be clamped in any position. The deckle-frames are kept in any desired position on the tranverse bars by pinching screws, and press down the deckle-bands close upon the wire, thus determining the width of the sheet of paper by

forming the lateral margins of the mould in which the paper is made. The stuff is guided laterally on to the wire web by a brass elbow-plate at each side, and the apron of the distributing box is adjusted to the width of paper by rolling up the sides on these elbow-plates. The elbow-plates are bolted by one end to the deckle-frames, while the other ends slide through sockets in the distributing box, and serve to regulate the width of its opening to that of the deckles. A pair of "slices" or thin transverse brass strips are fixed in the deckle-frames, with a vertical adjustment by means of which they can be brought within any required distance of the wire web to equalise the depth of stuff all over it. The water draining through the wire is caught in a zinc pan or "save-all," and is returned to the strainer by a centrifugal back-water pump. The wire is washed continually by three perforated pipes on its return below the table, and the deckle-bands have also a stream of water constantly playing on them near the pair of tightening rollers, the water being caught by copper troughs and escaping through india-rubber waste pipes into the drain under the machine. On leaving the table the wire web passes over two $3\frac{1}{2}$ in. brass rollers, between which the standards carrying the pulley shaft for the deckle-bands are fixed; the bearings are capable of vertical adjustment by means of screws, and the pulleys can be clamped on their shaft at distances corresponding to the width of the deckle-frames.

As the sheet of paper passes forward on the wire web, it is carried over two vacuum boxes F F, Figs. 25 and 26, which are strong wood boxes, 6 in. width and $4\frac{1}{2}$ in. depth, having a $1\frac{1}{2}$ in. drain pipe with a regulating cock carried down from each to some depth below the floor level, and a small stream of water is supplied by a $\frac{1}{2}$ in. cock to each end of the boxes and escapes down the drain pipe; the effect of this arrangement is to keep up a suction under the film of paper as it is carried by the wire over the boxes that drains it of a good deal of water, and at the same time greatly consolidates it. The vacuum boxes are so fixed to the side frames that they can be adjusted vertically; and they are made with false ends capable of being moved along the boxes by screws, so that they may be placed immediately under the margins of the sheet of paper on the wire. A

dandy roll G about 10 in. diameter is placed above, between the vacuum boxes, for the purpose of impressing any pattern or water mark upon the paper; it is driven by the wire upon which it is made to press, and is kept clean by a cross-board and felt for brushing the roll; the roll is formed of wire-work with the devices worked in relief upon it.

The paper then passes between the "couch" rolls H H, the upper one 18 in. and the lower one 12 in. diameter, which consolidate it by pressure, the upper roll having sliding bearings pressed down by weighted levers; these rolls are of brass, jacketed with felt, and the upper roll is scraped by a wood scraper covered with felt, and is continually watered along its whole length by a perforated pipe near the junction of the two rolls. The endless wire web passes over the lower couch roll in returning to the rear of the machine, and it is driven by this roll, which can be instantly disconnected from the engine if required. The web is supported behind the couch rolls by a guide roller, which has a sliding bearing at one end, with a transverse motion of about $2\frac{1}{2}$ in. by means of a screw and handwheel, for the purpose of checking any tendency of the web to run to either side by setting the roller slightly out of square with the line of motion of the web. All the portions of the machine from the end of the shake frame, and including the forward bights of the deckle-bands, are carried by a pair of cast-iron frames, which are securely bolted to two sets of cast-iron bed-plates that run the whole remaining length of the machine.

Pressing.—The newly formed sheet of paper, consolidated by the pressure of the couch rolls, sticks to the felt of the upper roll, and is caught hold of by the attendant at one corner and peeled off the roll by being held whilst the roll revolves; and it is then passed over a light wood roll on to a travelling band of felt 30 ft. length, which carries it through the first pair of press rolls shown in Figs. 20 and 21, Plate 18; the felt is carried over numerous wood rollers, with suitable rack stretching-rolls and guide-rolls. The press rolls are of cast-iron, 14 in. diameter, the bearings of the upper one working in vertical guides and pressed down by heavily loaded levers, giving a total pressure

including the top roll of nearly $2\frac{1}{2}$ tons, or at the rate of 68 lb. per inch width of the paper, the total pressure being varied according to the width of paper made. The rolls work in brasses set in strong cast-iron frames of such a form that the felt can readily be got out without taking out the rolls, and to facilitate this, provision is made for raising and keeping up the top roll. The paper in passing through sticks to the top roll and is peeled off as before, and then led over wood rollers down on to the travelling felt again, by which it is carried below a second pair of press rolls similar to the first pair. The paper is there lifted off the first travelling felt and transferred to a second one, by which it is carried through the second pair of rolls, but in the reverse direction, the side of the sheet that had previously been turned down being now turned up, and presented to the naked surface of the top roll, whilst the other side rests on the second travelling felt which is 14 ft. length. The press rollers are provided with scrapers or "doctors," with troughs underneath to carry off any water and to catch the dirt that falls off; and they are frequently, especially where highly-sized papers are made, also fitted with "soap doctors" or troughs filled with a solution of soap to prevent the paper sticking too tightly to the rolls. The lower rolls in both cases are driven by the engine, and can be instantly thrown out of gear by clutches; the top rolls are driven by contact with them. It is very important for the rolls to be true and to bear equally throughout, to prevent the paper coming away unequally damp or pressed. The first travelling felt gets by degrees impregnated with pulp, or rather with size or china clay &c., and provision is made in the standards that carry the press rolls for removing it for the purpose of a thorough washing without requiring the rolls to be taken out; but to avoid the necessity for this tedious process as much as possible, a partial washing is effected by a revolving beater with a couple of arms driven at a high speed under the felt; this beater thrashes the felt whilst a stream of water is made to play over it, and by this means a good deal of dirt is got rid of. The water from the "save-all" under the tube table, which contains a little fibre and a

good deal of colouring matter and size, is discharged by a wood shoot into a small iron cistern fitted with a self-acting float and connected to the back-water centrifugal pump, which delivers the water on to the sand strainer as previously named. The self-acting float prevents the pump drawing air if the supply of water becomes deficient at any time; but there is also a slide-valve actuated from the hand-side of the machine for throttling the suction pipe so as to vary the quantity of back-water returned at pleasure. An overflow lip in the pump cistern permits the surplus water to run off into the drain.

Drying.—The paper is then carried forward to the Drying Cylinders, shown in Figs. 20 and 21, Plate 18, and enlarged in Figs. 30 and 31, Plate 22. These consist of five pairs of cast-iron cylinders, 3 ft. 4 in. diameter and 6 ft. 6 in. length, with wrought-iron ends riveted in, and fitted upon hollow cast-iron shafts A A revolving in bearings that have vertical screw adjustments for taking up the wear. Steam of 5 to 10 lbs. pressure is admitted into each cylinder through a stuffing-box at one end of the hollow shaft, and the condensed water is taken up by a pair of scoops B B inside the cylinder, and delivered through the opposite end of the shaft into a self-acting water trap C, connected with a hot-water cistern near the engine. The cylinders are geared together by spurwheels on the ends of the shafts and intermediate pinions. The upper rolls are unclothed, but the lower ones have each an endless felt D D of 20 ft. length, embracing about three quarters of its circumference, and carried by five wrought-iron rollers, the two upper of which have a rack adjustment for stretching the felt, one of the two having also a finer screw adjustment; the lower central one is a guide roller with a lateral screw adjustment at one end. The sheet of paper delivered from the preceding press rolls, the end having been torn off at an acute angle, is taken by the leading corner, passed over a brass guide roller E at the side, and dropped between the felt and the first lower cylinder, under which the paper is carried, rising up at the other side, whence it is carried round the upper cylinder, to which it adheres and round which it is carried;

the paper is then led off by a pair of guide rolls to the second pair of drying cylinders, round which it passes in a similar manner, and again each of the three succeeding pairs of cylinders, when the polishing rolls or "calenders" are reached.

Calenders.—There are two pairs of Calenders, as shown in Figs. 20 and 21, Plate 18, composed each of two hollow cast-iron rolls, 14 in. diameter and 6 ft. 6 in. length, fitted with steam heating pipes and condensed water syphons very similar to the drying cylinders. The rolls run in bearings in massive cast-iron standards, and the upper rolls have sliding bearings held down by heavily loaded levers, giving a pressure upon the roll nearly the same as in the previous press rolls; the upper rolls are driven only by contact with the lower ones, which are driven by the engine. The paper is generally led over the top roll, back between the rolls, and out under the lower one of the first calender, and then if required it is led through the second calender, after which the sheet is finished and is ready for the cutting machine. The standards and frames of all the successive portions of the paper-making machine are fixed upon the continuous bed plates previously named, and secured by tee-headed bolts catching under a slot cast from end to end of the bed plates. Underneath the whole length of the machine is a pit which gives access to the several parts, and forms a drain under the wet end. A 2 in. water main runs along the floor on the hand-side, and supplies branches controlled by cocks for all the services mentioned; and a steam pipe is carried in the same way along the drying and glazing sections, for the supply of steam to the cylinders and rolls.

The calender rolls have to be made and finished with special care; they are cast of very hard close-grained iron, and after being turned as accurately as possible, they are ground together with emery by trains of grinding wheels provided for the purpose. In the manufacture of high class paper the calenders perform a very important part; they are made in many different ways, and now very generally of much smaller diameter, in stacks of a considerable number up to as many as twelve in height, the rolls being made of chilled American iron. The construction described in the present

case has been adopted on account of its simplicity and ease of management—matters of great importance in new countries where skilled machine-men are not obtainable.

Cutting.—The self-acting continuous Cutting Machine, which next receives the paper, is shown in Figs. 20 and 21, Plate 18, and enlarged in Figs. 32 to 35, Plates 23 and 24. It consists of two parts: the first being the circular knives for paring the edges of the sheet and dividing it longitudinally into the required number of strips or breadths. There are five pairs of circular shears C, fitted upon two parallel shafts, that are geared together at speeds proportioned inversely to the diameter of the shears, which are $5\frac{3}{4}$ in. diameter on the lower shaft and $9\frac{1}{2}$ in. on the upper. The lower shaft is driven by a pair of speed cones from the main driving shaft of the machine; the upper shaft terminates in a knob at one end, which is kept in its place laterally by a brass plate D, $\frac{3}{8}$ in. thick, dropping between a collar on the shaft and the end of the bearing, and the cutting action of the shears is stopped at any time by lifting out the brass plate and shifting the shaft and shears sideways $\frac{3}{8}$ in. Beyond the cutters are a pair of wood gathering rolls, the upper one having sliding bearings enabling it to press down upon the lower roll.

The second part of the machine is the Cross-cutting Apparatus, for cutting up the continuous sheet of paper into the required lengths, whilst it is being delivered at an uninterrupted rate of traverse from the paper-making machine; and for this purpose a definite length of the continuous sheet is measured off by an intermittent motion of the machine, and the forward traverse of the paper is thus momentarily arrested whilst a rapid cross cut is effected, when the machine proceeds to measure off another similar length, and the process of stopping and cutting is repeated. The measuring drum E is 3 ft. 5 in. diameter, and receives a reciprocating motion by a connecting rod from a crank F of variable stroke, which is driven by a pair of counter-cones N N from the main driving shaft O of the cutter; and a nice adjustment of the length of stroke of the drum is effected by the pin upon the drum shaft to which the connecting

rod is attached being made to slide radially with a screw and handwheel P. The paper passes over the top of the measuring drum and then hangs down the face of a vertical plate tangential to the drum, at the lower edge of which is a horizontal knife G, and immediately above this is a clamp board K that is pressed against the plate by strong springs and holds the paper fast upon it whilst being cut. The clamp board is then withdrawn by a pair of bell-crank levers moved by eccentrics, and the same movement brings down a pair of pressing rollers H upon the drum, causing the sheet of paper to be drawn forward to the extent of the forward movement of the drum. The pressing rollers are then released, and the clamp board is simultaneously pressed on to hold the paper during another cut, whilst the measuring drum takes its backward movement, sliding back under the sheet of paper and ready for the next forward stroke. The exact speed at which this is done, so as to keep pace with the rate at which the paper is made, is regulated by the position of the driving belt upon the pair of counter cones, upon which the belt is traversed by means of the screw and handwheel R and the pulley U. The continuous sheet of paper before reaching the measuring drum is made to pass under a wood "dancing" roll M, mounted in a counterbalanced frame, which by falling and rising alternately takes up the slack in the sheet of paper caused by the successive stoppages for cutting.

The cutting of the paper is effected by a knife I attached to a heavy horizontal cast-iron plate, suspended by connecting-rods, and working under the fixed knife before named with a scissors action, the cutting edge having a "draw" or inclination of $2\frac{1}{2}$ in. Motion is given to the knife by a pair of toggle joints connected to a crank T on the forward speed-cone shaft, so that at the moment the sheet of paper is clamped fast, the knife makes a rapid chop across the paper, retiring at once out of the way of its next forward movement. The centre lines of the toggles and cranks are so adjusted that the forward cutting motion takes place in much less time than the backward stroke. By this means sheets up to 40 in. length can be cut; and if a greater length is required, the connecting rod actuating the knife is transferred to a second crank S driven at half the speed

of the first one, and placed a little below and in rear of it. The paper is then measured down twice for each cut of the knife, but as the cutting motion would be too slow at a uniform speed of the crank shaft, this is driven by eccentric gearing giving a rapid motion at the cutting part of the revolution at the expense of a slow motion at the other part. The motions in this machine being all positive, and the paper being actually at rest whilst being cut, the result is great accuracy of work however fast the paper may be running; but in the case of water-mark papers, where it is necessary to keep the device in a particular part of each sheet, it is almost impossible to set the cutter so as to work exactly as fast as the paper-making machine, and the water-marks would consequently be apt to get out of place. To obviate this, a second smaller clamp board L to be worked by hand is fitted just above the first one, and by it the paper may be kept from passing down in front of the knife, so that a strip of any width can be cut off; the slack that gathers behind the hand clamp being pulled back in the return stroke by the drum, which thus takes as it were a fresh point of departure.

The only difficulty in working the cutting machine is getting rid of the electricity which is so largely developed by the drying of the paper. Short and light sheets decline to fall from the measuring drum unless the electric fluid is dispersed or conveyed away by conductors arranged for the purpose; but whatever paper can be got through it, is cut with great precision and at any speed. The cutting machine is frequently mounted on wheels placed upon rails, so as to be run forward out of the way when it is desired to reel the sheets for wall papers or for continuous printing.

The sheets as they are cut, if not too long, fall on to an inclined shelf, and are kept in order by a couple of boys sitting in front. For long sheets, such as newspapers, an endless travelling felt carries away the paper as fast as it is cut, and the common kinds are at once sorted as they pass along by a sorter placed on each side, the defective sheets being taken off the felt and the good ones carried forward to the packing room where they are at once put into bales. In finer papers the sheets from the cutting machine are carried

to the sorting room, where they are laid on large tables and looked over, generally by women; any sheets defective in colour or make are removed, and the good paper made up into packages for delivery, a 10 in. hydraulic packing press D, Fig. 1, worked by a hand-pump, being provided to assist in this work.

If writing paper is being made, it requires to be "polished," which is done by means of "wad rolls," shown at E in the general plan, Fig. 1, Plate 11, consisting of a pair of wrought-iron rollers, 14 in. diameter and 2 ft. 8 in. length, running at 3 revolutions per min., in massive frames. The bearings of the upper roll can be lowered or raised by $1\frac{1}{2}$ in. screws, and this roll is driven from the lower one by long toothed spurwheels, allowing considerable variation in the distance between the rolls. The sheets of paper are made up into piles or "wads" of 15 to 20 sheets, between each of which is interposed a thin sheet of zinc or copper very highly polished; and these wads are then passed through the rolls one after another, being brought back again by hand, and pressed as often as may be necessary to give the required degree of polish. When sufficiently glazed, the sheets are made up into quires and reams and cut to the size required in a simple guillotine machine F.

Steam Power.—The Ogi Paper Mill is driven by steam power, and the steam for all purposes is supplied at 60 lbs. pressure by three Cornish multitubular boilers, shown in the general plan, Fig. 1, Plate 11; each 5 ft. 9 in. diameter and 17 ft. 4 in. length, with single furnace flues terminating in 76 tubes, 3 in. diameter and 5 ft. 4 in. length. The main engine G, Fig. 1, is horizontal condensing, with 25 × 30 in. cylinder, running at 60 rev. per min., and indicating 140 H. P. when cutting off at $\frac{1}{4}$ stroke; the air-pump is double-acting, and worked by a prolongation of the piston-rod. The flywheel, 19 ft. 4 in. diameter, with 10 in. face, is geared and drives two mortice pinions 6 ft. 6 in. diameter on two lines of shafting, giving motion to all the preparing machinery, and to a 5 in. centrifugal pump, capable of throwing 400 gall. per min., and raising water from the river into a tank 25 ft. square, placed on a brick tower 26 ft. high; a second pump is provided as a

duplicate. The supply for the paper-making machine is by a separate 2 in. main from this tank, which has no other services on it, as it is specially important for the flow of water there to be uniform and unchecked.

The paper-making machine is driven by a 10 H. P. grasshopper engine, shown at H, Fig. 1, with $11\frac{1}{2} \times 24$ in. cylinder, running at a uniform speed of 45 rev. per min., and controlled by a sensitive Porter's governor. The engine drives by a belt, from a turned flywheel 8 ft. diameter, those portions of the machine preceding the formation of the paper sheet which run at constant speeds, or at speeds that do not necessarily vary with the rate at which the paper is formed; driving first a 3 ft. pulley on the upper shaft of the shake-gear, and this in its turn drives the shake and the knotters. A pulley on the engine crank-shaft drives the stuff pump, the crank-shaft of which serves as a countershaft for driving the agitators of the stuff chests; the centrifugal back-water pump and felt-washer are driven from the top shake-gear countershaft. The remaining portion of the machine is arranged to be driven at different speeds by means of four pairs of change wheels, which are fitted on to the slightly conical overhung ends of the shafts. The four different speeds thus given to the first press rolls are $13\frac{1}{2}$, 20, 26, and 32 rev. per min., corresponding to a make of 49, 73, 95, and 117 ft. per min. of the continuous sheet of paper. All the subsequent portions of the machine, including the final cutting machine, are driven from the shaft of the first press rolls, as shown by the pulleys and gearing at U U in Fig. 21, Plate 18; and the effect of this arrangement, which was suggested to the writer by Mr. T. Leigh, at one time manager of the Stowmarket paper mill, is that an adjustment of the rate of speed at any part of the machine beyond the first press roll leaves the speeding of the several sections following unaltered in relation to one another, and consequently the machine is very easily managed, as has been demonstrated by the facility with which Japanese and Arabs have been trained to work it. The minute alterations of speed that are necessary from variations in the nature of the paper are made by glueing on bits of felt to the faces of the belt pulleys; and although

this seems a rude method of regulating so nice a matter as the speeding of a paper machine, in practice it is found to answer better than any plan of expanding pulleys that has yet been devised.

The engine driving the paper-making machine is furnished with a small feed pump, by which the water condensed from the steam in the drying cylinders is pumped back into the boilers. The exhaust pipe of the engine is fitted with a loaded valve, putting from 5 to 10 lb. pressure on the exhaust steam, which is thus used advantageously for heating the drying cylinders; a small branch from the main steam pipe gives the means of supplementing this exhaust steam by direct steam from the boilers. In the arrangement of the several portions of the machine all the handles and adjustments that have to be used during the running are placed on the same side—the "hand-side"—so that the attendants have no occasion to go round to the other side on which all the gearing is collected, except for changing or adjusting speeds.

The machinery for the mill was ordered in August 1873, and it was shipped to Japan in June 1874; and the mill was got to work and paper made in August 1875. There was not any portion of the machinery of any consequence damaged or lost, and great credit is due to Mr. Frank Cheesman, by whom the erection of the mill and machinery was carried out in a remarkably short space of time, without the aid of any European mechanics, in an entirely strange country with a strange language. He has been favourably impressed by the intelligence and skill of the Japanese workmen with whose assistance the works were carried out, and by the high character of the native gentlemen to whom the mill belongs. The extent of the mill is 249 ft. length by 104 ft. breadth, besides the boiler house; and a mill of this size is considered capable of producing from 15 to 20 tons of paper per week of 144 hours; but this quantity is much affected by the quality and weight of the paper made, and the frequency with which the sizes and qualities are changed, as well as the management and the skill of the workpeople.

Mr. ANDERSON said the principal things to be remarked about this mill were the knotters and the cutting machine, which he believed were the joint invention of his late partner, Mr. Amos, and Mr. Clark, who was connected with Messrs. Joynson's famous paper mill at St. Mary Cray. The knotters had been fully described in the paper, and with regard to the cutting machine he might mention that it presented mechanical arrangements of that peculiar elegance and nicety which might be expected from Mr. Amos' well-known mechanical ability; it certainly was a remarkably nicely working machine. With respect to the paper-making machine, for the improvements in that he was indebted in a very great measure to the assistance of Mr. Thomas Leigh; and he thought now it was a very perfect machine indeed. Two similar machines had been erected in Egypt, and the Arabs there had learnt to work them without the least trouble. If a mill like the one described had been erected in this country, there would have been one, or perhaps two, "engineers" as they were called, to attend to the washers and beaters that prepared the "stuff," which was a most important part of the process; and there would have been two men to attend to the paper-making machine, skilled and trained men, one at the wet part where the paper was made, and the other at the dry part. But Mr. Cheesman had succeeded—by the assistance of Mr. Bottomley, a paper maker whom he found in Japan, but whose experience had been in America—in producing the paper of which specimens were exhibited, without the aid of any European or skilled artisan; this certainly struck him as being a very creditable achievement. The only thing complained of now in the Ogi mill was that they could not at once produce the full quantity; but any paper maker would know very well that in this country it would not be very easy to get a mill of this sort to work in two or three months, even with experienced workmen.

With respect to the samples exhibited, he had to thank Messrs. Bryan Donkin and Co. for the samples of rags cut by their cutting machine, which was a most useful and elegant machine, dividing the rags into regular small cubes. He also had to thank Mr. Marchant of the Phœnix Mills, Dartford, who had kindly

given the samples exhibited of rags in various stages, showing two different qualities of boiled rags as they came out of the boilers, and the same qualities opened out in the washing machine and washed, and also the same when they had been bleached. In one of the glass bottles exhibited the liquid "stuff" was shown in the state in which it was delivered from the beaters; and in another it was shown further diluted, having been caught as it flowed from the distributing vat of the knotters on to the shake frame, ready to be made into paper; these samples showed how finely the fibre had to be divided before it was fitted for the paper-making machine. To Messrs. Portal of Laverstoke Mills near Salisbury he was indebted for samples of the materials from which the Bank of England notes were made. With these very special care was taken; the samples showed the new clippings of rags which alone were used, the "half stuff" to which they were reduced without any bleaching whatever, simply by washing, and the final pulp from which the paper was produced. To Mr. Townsend Hook of Snodland he was indebted for the samples of straw and esparto, showing these materials as boiled, with the dark liquor or ley in which they were boiled; other bottles contained the same materials after washing, and also after bleaching. Esparto looked very like straw; it was by far the best material for many classes of paper that were made, but it was getting rather scarce. He showed also samples of the Japanese rags, and of the "half stuff" made from them at the Ogi mill; they were all cotton rags, made from cotton grown in Japan, and were splendid material for paper making. A sample was also shown of the wire gauze, sixty meshes to an inch, that the paper was formed upon.

Mr. C. E. Amos said the interesting paper that had been read was such a one as had not been produced before with regard to paper-making. The mill described in the paper seemed to him to be very well suited to the purpose for which it was intended—making a truly first-class printing paper, as shown by the specimens exhibited. It would also make a decent writing paper, but not writing paper of the best kind. The author had given him credit for one or two of

the machines illustrated in the drawings; he could only say though they looked very simple now they had cost a great many years' thought. There was one machine that he also took credit for, and that was the revolving rag boiler shown in the drawing, because he thought he had been the first to introduce the boiling of rags under high-pressure steam. Various means of boiling had been in use before; the old Manchester kieve was one of them, and there was a time in the early history of paper making when an open pan had been employed with a loose cover which was loaded with weights, the steam blowing out all round. When he became a paper maker himself, he reflected that if the rags could be put into a steam boiler there would be no loss of heat further than that required to bring the rags up to the necessary temperature; and as they could not be put into an ordinary steam boiler, he had constructed the separate revolving boiler described in the paper, and it had been found very efficient and had been rapidly adopted on all hands. Since that period there had been various forms of rag boilers, as mentioned in the paper; but he was sure the author was right in thinking that the boiler shown in the drawing was best adapted for the paper maker's purpose, and it was used in the best mills in this country; he said this not only as an engineer, but as knowing something about paper making.

Having examined the specimens that were exhibited of the paper made in the Ogi mill, he thought they were excellent, and the Japanese rags were very good. Mr. Cheesman's name had been mentioned in the paper, but he thought not strongly enough for the work that he had done, when the work of starting a new paper mill was considered. It was no easy thing even in this country to set a new paper mill to work, even with trained paper makers; therefore the greater credit was due to Mr. Cheesman for doing it in a country like Japan, and with the difficulties of a foreign language; great credit was due to him, and to Mr. Bottomley the paper maker.

Mr. E. A. COWPER remarked with respect to the paper-cutting machine that the first machine for cutting long sheets of paper had been invented by his father; it was not such a perfect machine as

the one now described, but it had all the essential elements of this machine. There were circular knives on a shaft to cut the paper longitudinally, on the same principle as in this machine; but instead of having a measuring drum for carrying the paper round, the paper was lifted so as to take up the slack. There was no dancing roller, but an actuated roller, which was lifted up by a lever so as to take up the slack every time, and then the sheet of paper was dropped straight down; it was then clamped, and the knife went through it; it was thus a horizontal action, instead of a vertical one. In those days the paper was not dried so thoroughly as now, and instead of having so many drying cylinders as were shown in the drawing, there were only a few; and the consequence was that the paper was always a little damp when taken off the machine and rolled up. Therefore the plain scissors-knife would not cut the paper at all satisfactorily, but tore it instead of making a clean cut. The way the knife was made was serrated, like a saw blade with a number of acute-angled teeth, each tooth being sharpened like a lancet, so that while the paper was held firm between two clamps the points of the teeth perforated it and cut through it. That would even cut damp paper very well, but the cut was not nearly so perfect as the present scissors' cut.

The PRESIDENT remarked that the serrated cutter just described seemed to have been somewhat like that of a reaping machine.

Mr. AMOS recollected having one of the late Mr. Cowper's paper-cutting machines under his charge at the Hatfield paper mill. At that time the paper was not so dry as now, because there were only four drying cylinders, and the speed was about 24 ft. per min.; in the present machine it was seen there were ten drying cylinders. Long before he left the business the speed was increased from 24 to 70 or 80 ft. per min., and therefore the old machine that would cut at 24 ft. per min. became very troublesome at the more rapid speed. In the first machine the circular knives worked into grooves, and did not act as shears. Even after the shearing action had been introduced, the knives were troublesome; they were large in

diameter and fixed upon very small shafts, and even when running at the low speed these shafts would vibrate so that a scissors-like action did not take place. Therefore he had reduced the diameter of the knives, and increased that of the shafts from $1\frac{3}{4}$ or 2 in. to something like $4\frac{1}{2}$ in. diameter; and consequently there could be no vibration of the shafts, and when once the knives were set up to each other they went very truly and right. That was one of the improvements in the present machine. With the positive motion of every part of the machine, accuracy of cutting was the result, and he had seen large wads of paper cut by this means with the ends as true as those of a pack of cards that had been ploughed.

Mr. COWPER, alluding to the knotters, said there had been several different forms of knotters made lately. The "bellows" knotter shown in the drawing was no doubt an improvement upon the old rapping knotter, in which, instead of the bellows working up and down and causing the water to move up and down through the slits in the perforated plates and so keeping them clear, the whole frame was lifted up and down, and had a rapping motion which made a very great noise; the knotter was moved through the water, instead of the water through the knotter. This bellows knotter was an elegant apparatus, and answered the purpose thoroughly well. Another form of knotter consisted of a long box of square or polygonal section, rotating on a horizontal spindle in a vat of pulp in which it was rather more than half immersed. The perforated plates formed the four sides of the rotating vessel, so that they were alternately immersed in the pulp and lifted out again; they thus cleared themselves at each revolution, and the fine stuff which was strained through the slits into the interior of the vessel was delivered from each end of it through the hollow spindle. He should like to ask for some information with reference to knotters of that kind, as to whether they were commonly found to work well in practice.

The mode of cutting the perforated plates for the knotters was rather a curious matter, and there were only a few makers of them. They were made by a very fine-cutting circular saw, which cut

through the thin metal forming the flat face of the plate, the back of the plate being cast with a series of grooves and bars, for giving the requisite strength of metal. The saw cut a slit in the bottom of each groove, where the metal was only about 1-16th in. thick, the edge of the saw just peeping through the metal on the face of the plate when the slit was finished. The saw itself being very fine was strengthened by a large washer on each side, of smaller diameter, so that the fine saw blade was left projecting to cut through the metal.

Another form of knotter was a circular one, consisting of a horizontal circular plate perforated with a series of very fine concentric circular slits, which was carried on a vertical shaft and caused to revolve within a cylindrical vessel containing the pulp, and at the same time was made to jump up and down—to pump, so to speak; in that way the water was made to go up through the slits in the downstroke, and kept the surface of the plate clear, the fine stuff passing down through the slits in the upstroke. He remembered seeing this form of knotter made by Mr. Clement of Newington Butts, immediately after the first knotter had been made by the original inventor, Ibotson.

In Ibotson's knotter the perforated plates were constructed in the form of a number of vandykes fitting into one another, which could be drawn closer together or further apart so as to alter the width of the V shaped slits; and the water was made to pass up and down through the slits by the upward and downward motion of the knotter.

Mr. AMOS said he had seen several of the square rotating knotters at work in Scotland, and the objection to them was this. The vat contained a large quantity of stuff, and it would be observed that as the finer portion of the pulp passed through the slits into the centre of the rotating knotter and away through the hollow axis, a residuum was left in the trough, and when it became necessary to clear the trough out there was a great deal of stuff that had to be wasted. That was why he did not like it, and he thought those who had had it must have felt the same objection.

The knotter described in the paper had been spoken very highly of, but there was another form that had been brought out by himself, and if it had been carried out further he thought it would have been the best that could be produced. It was a mode of forcing the pulp to ascend and pass up through a stationary perforated plate; there again there was this difficulty that the stuff got thick beneath the plate. To get over that, a small knotter of the ordinary kind was placed at a lower level, into which a quantity of the thickened pulp "knots" &c. from the box beneath the perforated plate was continually being drawn; it was there strained, the knots taken out, and the cleaned pulp returned to the principal knotter by the "lifters" of the paper machine. That would keep on for hours, and the knotter was almost self-cleaning. It had been tried at a paper mill at Ivybridge near Plymouth, and he had seen it working a day or two there in the most beautiful manner. The only objection found to it was this: that, there being no agitation of the stuff as it came off the knotter, some of the fine flour of the pulp gathered round the sides of the plate, forming little clots, and dropped off, causing a waste of the stuff. That might have been obviated if the plan had been gone on with.

He had also had the working of the circular knotter which had been mentioned by Mr. Cowper, and it had answered very well. The only fault was that it was too small for the work.

Mr. ANDERSON, in reply to the question that had been asked about the rotating square knotters, said he was informed by Mr. Leigh that Mr. Joynson got one of these at a cost of £1000, but the reason it was not used there was that it was apparently so weakly constructed that in revolving the joints between the plates opened more or less, and every time they opened they jammed a certain quantity of fibre in, and that gradually opened them more and more, and so made the thing unusable. But he believed Mr. Amos had given the true reason for its not being suitable for really good papers, and that was, that the stuff in the vat in which it worked got thicker and thicker, or at any rate the thickness varied, and that was fatal to anything like regularity of work; if it was wanted to produce a

good class of paper the regularity must be absolute as far as possible. Ibotson's knotters were he believed very popular; they were certainly very good. The upward-flow knotter which Mr. Amos had described had been adopted at the Stowmarket paper mill, and answered very well indeed there, except that it was altogether unsuited for straw pulp. It was a curious thing, but the bellows knotters described in the paper did not seem to answer for straw pulp; there was nothing like the common, rude, coarse, rapping machine for straw. But for the finer qualities of paper made from rags and esparto there was no doubt that the idea introduced by Mr. Amos was worthy of being further worked out. It so happened that he himself had not been able to do anything in that direction, because the machinery he had made had always been for abroad, for countries where the simpler the machines were the better, and where a very high class of paper was not aimed at.

He had not been aware that Mr. Amos was the original introducer of the revolving boiler for boiling rags; but that boiler as shown in the drawing was precisely the same as he himself found it when he joined Mr. Amos' firm, and he certainly thought it had proved as good an example of boiler as could possibly be made.

The PRESIDENT said he was sure the members would have pleasure in according Mr. Anderson their thanks for the very elaborate and exhaustive paper he had given; and moved a vote of thanks to him, which was passed.

The following paper was then read:—

ON THE YIELD OF WELLS SUNK IN THE CHALK IN THE CENTRAL PORTION OF THE LONDON BASIN.

By Mr. EDWARD EASTON, of London.

The question of Water Supply to London is so important and so interesting to engineers, that the writer does not hesitate to place before the Members of the Institution some facts, which in the course of a long experience he has gathered, and conclusions he has arrived at, in the hope that the statement of them may elicit additional information and valuable opinions on the subject. The geology of the London Basin has already been most ably and fully described by Professor Prestwich, Mr. Whitaker, Professor Ansted, and others; and it is not proposed to refer to it, except as far as the great divisions of the stratification affect the water-producing power of the basin generally.

The two great water-bearing divisions are:—first, the chalk denuded of superincumbent strata (except gravel), which receives the rainfall direct; secondly, the chalk covered by the tertiary deposits, which receives the rainfall, partly from the denuded chalk, and partly after its passage through the pervious beds underlying the London and plastic clays. It is to the consideration of this latter division that the present paper relates, and especially to that portion of it which is situated in the middle of London, within a radius of four or five miles from Charing Cross.

The chalk under London is always spoken of as taking the form of a basin; and this is strictly correct, as far as regards both its configuration of surface and lines of stratification along sectional lines from north to south. But it resembles a basin with a lip or spout to it in the other direction from west to east, the spout or outlet being the valley of the Thames below Woolwich, where the

river after passing through the tertiary strata resumes its course through the chalk itself. A transverse section of the Thames Valley is shown in Fig. 1, Plate 25, (as a diagram not to an exact scale) with a corresponding plan in Fig. 2; and a longitudinal section of the Thames Valley from Maidenhead to Purfleet is shown in Fig. 3, Plate 26; also two transverse sections of the Thames below London are shown in Figs. 4 and 5.

Were it not for two disturbing causes, it would be easy to trace the rainfall from its point of reception into the chalk to its outlet into the Thames, and so on to the sea; and an approximate estimate might be formed of the quantity so passing. But in the first place it is very difficult to determine the amount of obstacle offered by the deflection of the chalk to such a depth as it assumes under the tertiary strata, a depth varying from 100 to 300 feet; and in the next place there occurs a great fault in the strata on the east of London, which has a very marked effect upon the outflow of the water.

It is not possible to describe this fault in shorter or clearer language than that used by Mr. Whitaker* :—"The most important fault in the London basin is that along the valley of the Thames below London, with a downthrow on the north sometimes to an extent of about 100 ft., and perhaps more, which may indeed have had some effect in determining the course of part of that valley. It was seen in section in two railway cuttings south of Deptford, is proved by well sections at Greenwich, is lost sight of (? under the river) at Woolwich, is again shown farther eastward, again lost under the river, and last occurs on the northern side of the Thames near Purfleet and Stifford. In thus attempting to trace this fault for so long a distance I must be understood to speak with a little doubt, as there are two breaks in the chain, and as on the north of the river the beds are so much hidden by alluvium and gravel. In Mr. Mylne's geological maps of London no such line of fault is shown, but that at Greenwich is made quite distinct from that at Abbey Wood. I was quite unable however to trace any such lines

* Memoirs of the Geological Survey, Vol. IV., part 1, page 353.

of fault as those on Mr. Mylne's map, and it seemed to me much safer to connect the three separate exposures of Greenwich, Abbey Wood, and Stifford, in a gentle curved line."

The writer has quoted the whole of the passage, because it rather contradicts the facts published by Mr. Mylne in his careful map of the London Strata. Mr. Whitaker further says that "there may be other faults in this disturbed tract" (south-east of London), but that, "acting on the safe principle in geological mapping, not to draw a fault unless it is actually seen," none have been marked on the geological map of England.

The fault thus described, and indicated in the transverse sections, Figs. 4 and 5, combined with the fact of the chalk being disturbed, has caused a sudden alteration in the level of the water in the chalk; for whereas in the wells in Bermondsey on the south of the Thames, and Whitechapel and Shadwell on the north, the normal level of the water is from 70 to 90 ft. below Trinity high-water mark, the wells at Greenwich and those of the Kent Water Works on the south, and at Grays and other places eastward of the fault on the north side, have their normal water-line generally at about mean-tide level, or about 10 ft. below Trinity.

The other disturbing element in the flow of the water, as distinguished from the phenomena to be observed in what the writer will term pure chalk districts (such as the Brighton Downs for example), is that described by another eminent geologist, Professor Prestwich.* "With reference more particularly to the condition of the chalk underlying the tertiary strata, it is evident, in the many movements of elevation and depression which the crust of this part of the earth must have undergone, that those strata which form the immediate surface must have been far more shattered and fissured than those which are covered by a great weight of superincumbent deposits: the one portion would be extensively fissured and creviced, whilst the other would remain comparatively unbroken and entire. Therefore we cannot expect to find in the deep-seated mass of chalk beneath the tertiary strata the same

* Water-bearing Strata of London, p. 65.

facilities for the transmission of water as those which evidently exist in it where it constitutes the surface of the country."

Were it not for these disturbing elements, the flow of water in the chalk under London would doubtless follow more closely the general laws which govern it in pure chalk districts.

In the case of Brighton for instance, the rain which falls on the surface is to a greater or less extent, according to the period of the year, absorbed into the body of the chalk, and finds its way straight to the sea, partly through vertical fissures made during the course of ages in the solid rock itself, and partly along the horizontal lines of flints, which frequently in that district form unbroken beds of very considerable extent. The whole of the rainfall, except that absorbed by vegetation or given off by evaporation, percolates into the chalk, and has its chief outlet into the sea: just as, in the case of the London basin, its chief outlet would naturally be towards the river Thames at Deptford and below. When the chalk becomes full, the surplus water runs out at springs, which break out all along the great escarpment at the northern boundary of the South Downs, at Poynings, Plumpton, and in the Clayton tunnel of the London and Brighton Railway: just as, all round London, the overflow of the chalk finds its vent in the springs forming the rivers Wandle, Ver, Colne, Wendle, &c. But whereas the main body of water at Brighton runs into the sea underground, and only the surplus water finds its way into the open country: in the case of the London basin there is good reason for supposing that the great bulk of the rainfall on the chalk and strata feeding the chalk, situated to the westward of the fault above mentioned, runs out at these streams, and that only a comparatively small portion finds its way into the chalk under London. This view is strongly corroborated by the fact that,—whereas in London proper, where the chalk is covered with thick tertiary deposits, it is rare to meet with any well which will yield more than from 300,000 to 600,000 gall. daily (there is only one well the writer is acquainted with doing more than this, namely that of the Government Water Works in Orange Street, Leicester Square),—the wells and boring of the Kent Water Works give quantities varying from 1,000,000 to 5,000,000 gall. daily.

The fissures in the chalk being comparatively small, it follows that the inclination of the surface of the water will be such as to give the necessary head for the delivery of the water through them in proportion to their size. This rate of inclination in the Brighton chalk is as nearly as may be 40 ft. per mile. The writer has made careful observations as to this, the result of which was that the level of the water in wells situated in a straight line northward from the centre of Brighton to the Clayton spring described a flattened curve, which varied in its shape according to the season, but approximated to the rate of inclination above given. A record has been kept at the Brighton Water Works for upwards of thirteen years, which shows that the depth of water level in the wells varies with the rainfall; a diagram of this is shown in Fig. 6, Plate 27. Speaking generally, the depth of water level in the wells at Brighton is at its maximum in March each year, and the minimum is in October to December; but this is dependent upon the season, it being observed that the curve formed by the depths of the water follows that of the rainfall at an interval of about four months. Very much the same phenomenon takes place in the London basin, where again on the average the lowest time in every year is March, and the highest November to January.

The disturbing causes have produced also another result in the case of the London basin, namely the uncertainty of finding water in any quantity. This is particularly shown by the difference in the yield of the well at Trafalgar Square and at Combe and Co.'s Brewery in Long Acre, the former giving above 600,000 gall. daily, whereas the latter at the distance of little more than a mile does not afford a supply of one tenth the amount, although the water level is lowered very considerably more.

It is very difficult to determine also how much of the water obtained from the wells sunk through the tertiary strata into the chalk is derived from the chalk itself, and how much from the sands between the plastic clay and the chalk. At many places the quantity from the sands is very much in excess, as for instance at Truman and Hanbury's Brewery, Spitalfields, where out of a daily

yield of 120,000 gall. only 10,000 gall. or one twelfth of the whole comes from the chalk itself. The writer's opinion is that in every well sunk in the centre of the London basin, where the chalk is covered by the tertiary sands, there is a very considerable admixture of water from these sands with the chalk water proper, if indeed this admixture is not quite general all over the district. The chief reason for coming to this conclusion is that,—whilst the analysis of water derived from denuded pure chalk invariably shows a hardness according to Dr. Clark's test of from 14 to 18 degrees, arising to a very great extent from the presence of carbonate of lime and to a smaller extent from chloride of sodium,—the water obtained from boreholes or wells sunk through the tertiary strata is generally soft, and varies from 3 to 8 degrees. This does not arise from the absence of mineral matters in solution, so much as from the presence of alkalis which neutralise the hardening effects of the salts. Thus, whereas the average analysis of pure chalk water would be somewhat as follows:—

Carbonate of Lime	13·00	gr. per gall.
Sulphate of Lime	1·20	„
Chloride of Sodium	2·50	„
Silica	1·00	„
	17·70	

or say 18 gr. per gall.,—the average analysis of the deep-well water under the tertiary strata would be

Carbonate of Lime	3	to	8	gr. per gall.
Carbonate of Magnesia	1½	„	2	„
Carbonate of Soda	6	„	18	„
Sulphate of Soda	24	„	6	„
Sulphate of Potash	1	„	13	„
Silica	½	„	1	„
Chloride of Sodium	10	„	20	„
	46		68	

or from 40 gr. to 70 gr. per gall.

Another point to be observed in connection with all these wells is that the level of the water in them is steadily lowering, as the sinking of new wells in the district causes a larger amount to be drawn from the strata. This has been observed in nearly every

well which has been steadily worked; and several cases are known where wells have become disused, owing to their having run dry.

From all these facts the writer draws the conclusion that the passage of the water through the fissures of the chalk under the tertiary strata is very much impeded; and that, although there is an immense surplus of rainfall percolating into the chalk all round London, comparatively little finds its way into the chalk beds beneath the centre of London; and that what does so pass is very much mixed with water which has either come direct from the outcrop of the tertiary sands and through them into the wells, or has in its passage from the upper levels of the underlying chalk to the lower parts of the stratum gone through some of those sands. It is evident that no great quantities of water can be expected under London itself, certainly not more in the writer's opinion than will be wanted for manufactories and large consumers; and that any great addition to the general supply of the metropolis from the chalk must be looked for from the outlying districts where that stratum is denuded.

Mr. EASTON drew attention to the peculiarity which was shown in the last three months in the diagram exhibited of the rainfall and the water level in the wells at Brighton. It would be seen that in the present year 1876 there had been two great jumps up in the water level, arising no doubt from the enormous rainfall of last July and November; there had thus been two rises in the water level during the first quarter of the present year, instead of one as had almost invariably been the case in previous years; there was a distinct double rise, following from two sudden rises in the rainfall of the half-year before.

Mr. E. A. COWPER mentioned that he had a section through a large number of the wells in London, showing the depth of water, which had been taken some years ago; and he could quite corroborate the statement in the paper that the general level of the water in the deep wells throughout London was decidedly lowering.

The PRESIDENT asked if Mr. Webb would give some information with regard to a very peculiar well at Camden Town belonging to the London and North Western Railway.

Mr. F. W. WEBB said the well referred to had been pumped dry last year, and had now been deepened, and a fresh supply was obtained of about 100,000 gallons a day. But the quality of the water was too soft for locomotive purposes; it could not be used for locomotives at all, unless the boilers were new or perfectly clean, with no accumulation of scale. If a charge of that water were put into the tender, the engine would prime and throw all the water out of the boiler; a great quantity of soda was contained in the water.* He had tried at Watford a short time ago softening the chalk water there by the lime process; an engine that was very foul indeed from working with hard water on the Rickmansworth Branch was supplied from a tank in which the water had been softened, and at the end of a month the boiler was perfectly clean; the soft water had taken out the whole of the deposit, and not a handful of scale could be got when the boiler was washed out.

Col. CLAY enquired whether at the Brighton Water Works there was any tendency for the water to become salt from the infiltration of the sea water. In Liverpool there was a great tendency to salt up the sandstone rock that formed the filter bed through which the

* The following is the analysis of this water :—

Sulphate of Soda	13·0	gr. per gall.
Carbonate of Soda	17·6	„ „ „
Muriate of Soda	11·1	„ „ „
Carbonaceous matter and trace of Silica ...	2·3	„ „ „
Total solid matter	44·0	gr. per gall.

water came. He had sunk four wells there in succession, the first being at the south end of Liverpool; and when Mr. Stephenson reported in 1848 upon the water supply of Liverpool, the water in that well was of very considerable purity; but within five years of that time the water was so salt that it could not be used for boilers. A well was then sunk 150 feet further away from the river, and that also in a short time became salt. As a considerable quantity of water was required, he then went to what was considered to be beyond a small fault running through the sandstone rock, and thought that by going to the other side of it the salt water from the river would be cut off; but there was some connection through the fault, and it was very soon found that that well also became salt. A fourth well was then sunk, in which very great pains were taken to keep all the sea water out. A 12-inch bore hole was carried down deeper than the bottom of the lowest part of the river Mersey, and in the upper part of the hole the top water was tubbed out by iron and cement; but it was still found that the well water soon became salt, and that the height of the tide could be told by the height of the water in the well, the rise and fall in the well being influenced by that of the tide.

Mr. C. E. AMOS mentioned that about 1837 his partner Mr. Easton had been engaged in sinking the well at Camden Town that Mr. Webb had spoken of, and he recollected very well the difficulty they had with the water and its unfitness for locomotive purposes, so much so that it could not be kept in the boilers on account of priming. To get over the difficulty the railway company arranged with the canal alongside, by putting down a double-acting pump with separate outlets and inlets, so that in one stroke the pump would take a measure of water from the canal and put it into the tank for the locomotives, and the return stroke would take the water from the well and put it into the canal.

Mr. WEBB said that for a long time the present yield of the well at Camden Town had been only sufficient water to supply the two hotels at Euston station. It was so soft and in such demand that

there had been none to spare for mixing with the canal water for locomotive purposes.

With reference to the saltness of wells near the sea, he might mention that he had sunk a well a short time ago at Carlisle on the land side of the dip of the basin that Carlisle lay in, and found by analysing the water in this well and in the well of the prison, which was on the sea side of the dip, that the prison water contained 12 gr. of common salt per gall., but the water in the new well had only $1\frac{1}{2}$ gr.

Mr. C. HAWKSLEY, referring to the diagram exhibited of the water level in the wells at Brighton, thought the second rise of the water in the year 1876 was due to the rainfall in February and March of that year arresting the usual depression, rather than to the second heavy rainfall during 1875; because the lapse of time between the termination of the second heavy rainfall in 1875 and the second rise in the level of the water in 1876 appeared to be greater than had been the case in former years.

Mr. ERNEST SPON said that, having paid considerable attention to the flow of underground water, he was entirely of the author's opinion that more than one main fault ran through the London district, particularly in the south eastern division. He was not sure that the long line which Mr. Whitaker seemed to think was a single fault, though guarding himself against definitely pronouncing it so, was not really a double fault; and if that were the case, there was no reason whatever why other faults of a similar description should not exist to a certain extent. That would explain the apparent inconsistency, mentioned in the paper, between wells which were in immediate proximity, and yet one, which was perhaps sunk to a greater depth than the other, would yield little or no water compared with that which the other yielded; while there were wells similarly situated not interfering in the slightest degree with each other's yield. There was a notable instance of this in the case of the wells sunk at the two breweries one on each side of Stockwell Green, the wells being separated by a distance he thought of about 100 yards.

One well he believed was sunk 211 ft. in the tertiary strata, and 150 ft. into the chalk, and yielded he was told about 46 gall. per min. The other well was sunk 210 ft.—practically the same depth—in the tertiary strata, and only 100 ft. into the chalk—that is, 50 ft. less than in the neighbouring well—and yielded 33 gall. per min. The yields over the district varied he believed to a very great extent; and he wished to call attention to the difficulty there was in ascertaining the actual yield of many wells in London. The wells were sunk in many instances by private firms, and often at great expense, and they did not like the yield to be known, in case it might come to the knowledge of other parties in the same business. In many instances too such a large sum of money was spent about wells without any adequate result that an additional incentive was furnished to keep the matter close; so that there was a considerable difficulty in ascertaining what was the actual yield of wells sunk in the district to which the paper referred. He had hoped to hear from the author something more about the actual yield of a good many wells in the London basin; but he presumed he was labouring under the difficulty now alluded to. He had himself been at considerable trouble to collate the statements made by various competent authorities. It had been stated many years ago by Professor Prestwich, who took considerable trouble in the matter, that the yield of the principal wells in the London district was, as far as he could ascertain, from 80 to 120 gall. per min. His own experience led him to feel that this was a little over-estimated, and that the yield under most circumstances did not amount to more than 100 gall. per min.; when sinking in the chalk he never expected to meet with more than that quantity, and he should consider himself fortunate if he came across a fissure and got more.

He should like also to know from the author, if possible, what he supposed was at the present time the level of the water in the wells in the London basin; he was aware this was not at all an easy question to answer.

With respect to the flow of water through the fissures of the chalk, of course that was very large. The flow was very much impeded when the fissure, as often occurred, narrowed and enlarged

and then narrowed again. That was shown very well by the practice of the well sinkers in the chalk, who when they found a fissure invariably followed it up—if they were working in their own interest—and endeavoured to enlarge it as much as possible, so that if they came to a contraction they broke it away, and the fissure under those circumstances in nine cases out of ten gave a considerably increased supply.

Mr. EASTON said the depression of the water in the London wells, that had been referred to, was known to be a fact by everyone who had experience in pumping water from the chalk under London. At the Bank of England a constant record was kept, which showed this. The water in other wells that he had been connected with—Messrs. Clowes', Duke St., Stamford St., for example—was constantly going down, and the pumps had to be lowered. The Covent Garden Market well had been abandoned because the water had fallen below the bottom of the well and so was beyond the reach of the pumps; and water had now to be obtained from the water companies for the supply of the market. The same was the case at other places, such as the Club Chambers in Regent Street. It was the fact that the water level had been gradually lowering, as a necessary consequence of more wells being sunk in that particular source from which the water was derived, and more water being taken from it.

With regard to the question asked about the water at Brighton becoming salt, there was no risk of that kind either at Brighton or Ramsgate or any other seaside place where the water came from the chalk, if the wells were not sunk below the proper depth. At the Brighton Water Works the tunnels driven out from the bottom of the wells were at the level of low-water mark; and the water taking a certain gradient from the interior of the country to the sea, the pressure drove the fresh water out against the pressure of the salt water. If the wells, which were at a distance of a mile from the sea, were to be sunk deeper, so as to reverse the gradient, then no doubt the salt water would get back into the wells; in fact in one instance a well had been sunk to too great a depth, and instead of the tunnels being driven further the pumping of the water was

continued to too great an extent, and the water was absolutely drawn in from the sea into the well, so that the well had to be abandoned and a new pumping station made. At Liverpool the case was totally different; if he remembered rightly the water in the wells there was considerably more than 100 or 150 ft. below the level of the Mersey, and there was a very great risk of drawing salt water through the fissures.

With regard to the deduction to be drawn from the two rises or jumps shown for the present year in the diagram of the water level in the Brighton wells, he thought the explanation he had given was correct; the interval between the rainfall in July and the first rise in the wells in the present year was about six months, and the interval between the November rainfall and the second rise was about four months. Having studied the diagram a good deal he thought the greatest height of water in the wells followed generally three or four months after the greatest mass of the rainfall.

As to the particulars asked for about the wells in London, he had already collected a great many figures and had hoped to be able to prepare a list of the wells with their yield and their level of water; but he had found it absolutely impossible to get anything like reliable information. Some parties had been very kind in giving all the information he had asked for, and very valuable it was; but others had declined to do so, and therefore he had not attempted to draw up a table, which, unless it were quite complete, would not be of any great service. But from the calculations which he had been able to make, knowing really what must be consumed at different places, and judging from his own knowledge of the district, which was considerable, he believed that, taking the four zones included within circles described with radii of 1 mile, 2 miles, 3 miles, and 4 miles from Charing Cross, the quantity of water yielded by the wells was as nearly as possible about a million gall. per day in each zone in the dry season—perhaps a million and a quarter in the innermost zone. He agreed that under London itself, with the exception of that part of the chalk which was denuded, as at the waterworks at Deptford and at Grays, it must not be expected to get out of one well much more than 100 gall. per min.; this

was probably about the proper estimate. Here and there more might be got: considerably more for instance at Barclay and Perkins' brewery Southwark, and at Trafalgar Square. At Meux's brewery in Tottenham Court Road he believed a bore-hole had been carried down by the diamond rock-boring company to 930 ft. without getting water.

The level of the water in the wells he was not able to give any reliable information about, because it varied so very much according to the amount of pumping, and depended also upon whether the springs were yielding copiously or not. In those wells which were very much tried, where the water was drawn out to a considerable extent, it was never allowed to get up to its normal level, and therefore it was almost impossible to ascertain what would be the normal level. He thought what he had stated in the paper—from 70 ft. to 90 ft. below Trinity high-water mark—was about the normal level in the middle of London. He had hoped to be able to draw a line to represent the water level upon the longitudinal section exhibited, but he had found it was quite impossible to do this from his own data; the line was too irregular, and would really have been no continuous line at all. At Maidenhead the water ran over the surface out of the chalk, and about Cliefden and Lord Boston's estate near Maidenhead it ran into the river in the form of springs; and from there to the deep pumping wells under London the water level got lower and lower, taking more or less a gradually descending line, which was like the gradient he had spoken of in the case of Brighton, only that the position of the water level in the London basin was disturbed by the difficulty of the water getting through the different fissures of the chalk.

The PRESIDENT proposed a vote of thanks to Mr. Easton for the interesting paper he had given, which was passed.

The PRESIDENT announced that the Summer Meeting of the Institution would be held at Birmingham in July, at the time of the Royal Agricultural Society's Exhibition there.

A vote of thanks was passed to the Council of the Institution of Civil Engineers for their kindness in granting the use of their rooms for the meeting.

The Meeting then terminated.

SPECIAL MEETING
ON THE PATENT LAWS.

May 1876.

A Special Meeting of the Members, called by requisition for the purpose of considering the Patents for Inventions Bill then before the House of Commons, and adopting resolutions and a petition to Parliament on the subject, was held at the Society of Arts, London, on Tuesday, 16th May, 1876; John R. Ravenhill, Esq., in the Chair.

The notice convening the Meeting having been read,

The Chairman said that, owing to a pressure of business, the President and other members of the Council were unexpectedly prevented from attending the meeting. At the former special meeting held upon the same subject in June 1875, Mr. Bramwell, who was in the chair, remarked in reference to the Patent Bill then under consideration:—"Nevertheless it might be revived next session, and then he hoped that the resolutions and deliberations of the present meeting would have their weight, or, if need be, that the members of the Mechanical Engineers' Institution would meet next session for the purpose of recording their protest once more against the passing of a bill so injurious as he firmly believed such a bill as this would be if it became law, not only to inventors but to the country itself." The present meeting had been called for the further consideration of this subject.

Mr. R. H. Tweddell said he would not offer any remarks on the question of the patent laws—whether they were desirable or not—as that was not the object of the present meeting; but they were he trusted now met to confirm the proceedings of the special meeting held last year. He would therefore, before moving the resolution he had to propose to the meeting, merely mention one or two facts to

show the necessity of not ceasing to agitate against the bill which was shortly to come on for discussion in the House of Commons. He thought he could not do better than quote what had been said by eminent men who had charge of the bill or were otherwise connected with it. From a report of Lord Cairns' speech he was stated to have said:—"I have never been a strong advocate for patents;" and after some other remarks in a similar strain he added:—"I do not speculate on what may happen in the course of years." Lord Cardwell had said:—"He liked the bill for what it did and undid. What it undid was that it would put an end to the present system of patents, which was injurious both to the inventor and the public, as well as the manufacturing industry of the country. And what it did would be to establish in its place a system which he ventured to say would be instrumental in obtaining the object he desired—the abolition of patents altogether." To quote from some remarks by an eminent peer in a letter to a friend on this question:—"I am the less inclined to take any part in the discussion of the bill because I adhere to the opinion I adopted many years ago when I had occasion to look into the subject, that our whole system of legislation with respect to patents is wrong, and that it would be better to put an end to granting them altogether. It is pretty clear that is the opinion of the Chancellor himself, and that he would prefer a simple repeal of the existing acts to such an amendment of them as he proposes, which he only brings forward in deference to the strong wish expressed by those interested, and supported by the public."

Thus it seemed pretty clear what the effect of the bill would be if passed: certainly not in consonance with the views of the Mechanical Engineers as represented at the previous special meeting. The discussion on the resolution which he now brought forward would prove whether in any respect the opinions then expressed had been modified.

The resolution was as follows:—

That, inasmuch as the Patents for Inventions Bill 1876, now before Parliament, does not meet the views of the special meeting of the Institution held on the 28th June 1875—Resolved

That a petition be forthwith presented to the House of Commons, embodying such views in so far as they are applicable to the present bill; and that the President be authorised to sign the petition on behalf of the Institution of Mechanical Engineers.

That the views of the members of the Institution be expressed in the following terms:—

That the petitioners are of opinion that many of the provisions in the Patents for Inventions Bill 1876 proposed by the Lord Chancellor are contrary to public policy, and an interference with the admitted rights of inventors and others connected with property in inventions.

That the bill would be much worse in its operation than the act of 1852, for the following reasons, amongst others, namely:—it would give unlimited power to the Lord Chancellor to stop patents, as well as to a large extent to control the terms on which they should be used;—it would not appoint paid commissioners to manage the office;—it would abolish provisional specifications;—and it would appoint examiners, who would be practically irresponsible, who would have the power of reporting against the applications for patents, on grounds of which they frequently could not possibly judge.

That any preliminary examination of applications for letters patent which may be hereafter instituted should not extend beyond the questions whether the specification is clear, and whether the invention is open to objection on the ground of want of novelty, regard being had to prior publications in the patent office.

That an adverse report should not disentitle an applicant to a patent.

That in lieu of the proposed publication of reports, which would in many instances operate unjustly, the applicant should merely be required to insert in his specification a clear and definite reference to, and an acknowledgment of the existence of, the prior matter found and pointed out by the patent office officials, with a clear statement of what he claims notwithstanding.

That, inasmuch as the changes in the law, proposed by the bill now before Parliament, differ materially from the recommendations of the Royal Commission of 1865 and of the Select Committee of 1872, it is expedient that no legislation on the basis of the bill now before Parliament should take place, without special reference to a Select Committee.

Mr. T. R. Crampton, in seconding the resolution, said the object now was to pass a resolution embodying the resolutions that were passed last year. It appeared that the bill was hardly altered from that of last year; as he understood it, engineers as a body objected to the bill entirely, as being very injudicious and one which would be, if passed in its present state, very prejudicial both to themselves and the public.

Mr. W. Smith wished to call attention to the necessity of dealing with this question on a different footing from that on which it had been put by the seconder of the resolution. It was perfectly certain that if a bill were entirely objected to there was only one thing to be done,—to get it withdrawn; but certainly that was not what was wanted. He differed from the seconder on that point, because what was wanted was legislation in a certain direction, which had been indicated not only at the previous special meeting of the Institution, but also at several meetings held at the Society of Arts, when the question was discussed whether patents for invention were a proper mode of rewarding inventors for their study and devotion. He thought that subject had been dealt with very exhaustively on those occasions, and, as the proposer of the resolution had very properly put it, the present meeting was not held to discuss *that* question. That had been settled so very satisfactorily in the affirmative, that he thought the question now was whether there should be such a modification in the present bill as would meet the views of those who had taken an interest in the question, not only on behalf of inventors but also on behalf of the manufacturing industries of the country, to which industries this country owed its great position for wealth and power. But for the protection afforded to inventors and inventions, this country would be in a totally different position from that which it now occupied. He thought therefore that there must not be a simple negative to the bill, but it must be determined what was wanted in the shape of modifications in the Lord Chancellor's bill, which was, he considered, a most objectionable production as a legislative measure, and violently opposed to public policy.

Mr. W. E. Newton quite agreed with the last speaker in reference to the way of dealing with this question. He thought it would be very improper, in a meeting of the Institution of Mechanical Engineers—a representative body of the talent of the country in mechanical engineering—that this question should simply be met with a negative. He considered it was their duty to point out what things ought to be done, and not simply to give the bill a negative. He did not quite agree however in all the objections

which had been expressed with regard to this bill; it certainly was an improvement on the bill of last year; and he thought if the question were fairly dealt with, and certain alterations were put clearly before the House of Commons, the bill would be made a very fair act for the protection of industry. There was no doubt the present law was defective in many points. He saw that, since last year, there had been one or two things put into the proposed bill which certainly were beneficial to the interests of inventors at large; but he was quite ready to agree in the opinion that this bill, if it passed in anything like its present shape, would be a very bad thing for the manufacturing industry of the country and for inventive ingenuity at large. It appeared to him desirable therefore to set forth, in clear and straightforward language, what it was thought ought to be done with reference to certain clauses.

He held, and he believed it was held pretty generally among patent agents—who were perhaps as good judges of the question as could very well be found—that the existing act of 1852, if it were really properly carried out, would do almost as much as the present bill proposed to do, without laying the inventor open to some of the difficulties that this bill would involve him in; and the reason was that in the existing act there were powers given to the Commissioners which they had never exercised in the least and had never tried to exercise. For instance, the great feature of the bill was to enter upon a very exhaustive examination of patents, for the purpose of throwing out what might be called frivolous inventions; but if that were really the intention—if it were really desirable that a very exhaustive examination of patents should be carried out—this could be done very well under the present law, because the Commissioners had all the power to appoint all the officers necessary for any such purpose, whether they were called examiners or clerks; he was sure all who knew anything about the present law would agree with him that it was quite possible to appoint all those officers, and to have as exhaustive an examination of the subject as could possibly be done under the proposed bill. But the question now was, why was not this done; and he thought the reason could be shown. The patent office was an office administered in a very peculiar way; there was

no master, but all were clerks, and nobody had any power to do anything except simply what he was told. Mr. Bennet Woodcroft was supposed to be at the head of the office; but he took great care (and he was justified in it) not to do a single thing he was not compelled to do or that was not set down for him to do. Now if there were Commissioners sitting there, with power to order certain things to be done, a much more satisfactory state of things would probably be obtained than at present existed. The present bill proposed to empower the Queen to appoint three or more commissioners; but these commissioners were supposed to act as honorary commissioners and were not to be paid. He himself was of opinion that unpaid services were not worth much. What was wanted was, not a number of gentlemen high up in the legal profession—the Lord Chancellor, the Master of the Rolls, the Attorney and Solicitor General, the Attorney and Solicitor General for Ireland, the Lord Advocate and Solicitor General for Scotland, and all those gentlemen who never came personally and had not done so since 1852. There was no one of these who had ever taken the least interest in the working of the patent law, except the Lord Chancellor, the Master of the Rolls, and the Attorney and Solicitor General, for the time being; and until the present government came into power not a single commissioner had ever been seen inside the patent office for eighteen months. But if there were three or four paid commissioners, who were responsible for the proper working of the law, then most likely things would be carried out in a very different way. Of course he was quite willing to admit that, if it were possible for the present commissioners, with their multifarious duties, to attend to this business, they were men who were perfectly competent to do it, so far as making rules and orders was concerned; but they were not the men to administer, they had not the time, and that was one of the reasons why it became necessary to make further alterations in this bill. He had met a number of other patent agents to discuss this question, and they had come to the conclusion that to refer patents or inventions to the law officers of the crown was simply a delusion; they could not possibly attend to the matter, the business was increasing day by day, and to suppose that those

gentlemen with their many duties could possibly enter into it was a complete delusion. But if there were three paid commissioners who could appoint a proper and efficient staff, things would probably be properly attended to, but not otherwise.

It had therefore been suggested that wherever the words "law officer" occurred in the bill the word "commissioners" should be placed; so that when the examiners were appointed they should report to the commissioners and not to the law officer. The main thing he wanted to insist upon was, that there should really be three paid commissioners, and that they should be appointed not for their legal knowledge, which was not wanted, but for their scientific knowledge; and that they should have power, together with the other commissioners, of course under the present act, to make rules and orders for conducting the business of the patent office. He did not agree in putting a negative on the proposed bill entirely, because he thought this could not be successfully done, as the present government, if determined, could carry the bill; but he thought it was quite possible so to alter and modify it and correct mistakes as possibly to get the things done which were necessary.

The Chairman remarked that it was proposed to refer the bill to a Select Committee; and his own feeling was that the thin end of the wedge would be more likely to be introduced if the bill went before a Select Committee than if it were attempted to alter the clauses and get some one to argue in favour of the alterations in the House of Commons when the debate came on. He thought that evidence before a Select Committee would be far more beneficial than attempting to alter clauses.

Mr. Crampton did not intend his observations to go to the extent of throwing out the bill. He felt that, if such an important matter could be brought before a Select Committee, so many new facts had arisen since the last Select Committee was formed, that he was perfectly sure proper legislation would follow the appointment of such a Committee.

Admiral SELWYN said that, as a Vice-President of the Inventors' Institute, he had attended several meetings held with the object of discussing this patent bill; and after considerable examination and discussion the conclusion had been arrived at that the bill betrayed strong symptoms of "mala fides," that is, that it was brought forward for the purpose of extinguishing patents for invention under the colourable pretext of improving and amending. It had therefore been decided that the best course to take—and he would urge it for the consideration of the Institution of Mechanical Engineers—was simply to fall back on an affirmation of the principles on which patents were granted for inventions, and to show broadly that it was not the claimer of the patent but the public who required such a stimulus as could be given by protection of inventions, in order that the state might profit by invention. This was the view on which the statute of monopoly had been passed, and this had been the view on which previous legislation had taken place; but if the Lord Chancellor was, as he appeared to be, convinced of the necessity of doing away with the patent laws altogether, it could scarcely be expected that any modification of the bill would be successful so as to suit the interest to which he was opposed. The meetings to which he had referred had therefore affirmed some very broad principles. First, that public polity required that inventions should receive protection. Secondly, that that protection ought to be put on the same basis as protection to all other property realised by industry in the state. Thirdly, that a correct registration of inventions should be made at the patent office; that the duration of patents should be assimilated to the duration of copyright; and that the fee to be paid on those inventions—in consideration of the fact that every successful invention contributed an enormous amount in income-tax to the state, besides the profit made on every transaction under it—should only be such as had been proved to be sufficient for the purposes of registration and examination in the United States, or something very nearly approaching to it, in order, not to relieve the pockets of those who were perfectly well able to afford the outlay on successful patents, but to enable the technically educated brains of the workman in manufacturing and mechanical

engineering to receive due protection whenever he exerted them to good purpose. In such a way alone could the wealth of the state be built up; and it was for these reasons that this broad view of the question had been taken. It was felt that they could not hope to go to the House of Commons and fight clause by clause of this bill with which they materially disagreed; but they could hope to bring about such a state of feeling in the House of Commons as would cause it to be seen that the principle was not a wise basis to legislate upon, that inventions neither needed nor deserved protection. He suggested for the consideration of mechanical engineers whether they were not above every one else interested in promoting every protection that could be given to inventions, for in no other than the mechanical arts were so many inventions of great value made, dropped, and lost, simply because the workman who devised what he called in his shop "dodges" never saw his way towards getting them protected, and so they dropped out of existence altogether. Patents were devised to prevent such cases recurring.

The question whether patents should be subject to the law officers or not had been ably put by a previous speaker. It was certain that no department in the state would be well administered if it had to be constantly referred to them. Suppose, for instance, that the admiralty or the military department were always to be referred to the law officers or the judges, all of whom were known to have more work in their own departments than they could overtake; what result could be expected? what therefore was the use of piling on more work for the mere purpose of keeping great names before the public as heads of departments? The real working men of the departments were those who were familiar with the everyday transactions in them.

The resolution he hoped would receive the full support of the meeting, except as to the clause about referring the bill to a Select Committee. He was sorry to say that those committees had arrived at conclusions which were the reverse of being secure in their grounds or correct in their reasoning. Persons strongly interested in taking inventions from inventors without paying for them appeared before those committees and worked very strongly indeed; but

inventors and the public, the persons principally affected, were really then represented very feebly as to numbers, though perhaps strongly as to intellect. Having gone through all the recommendations of the previous committees, he was of opinion that they had arrived at conclusions generally which would entitle the Lord Chancellor to think that no protection at all was better than such protection as those committees recommended. He thought that a general petition, coming as it did from many other bodies, might fairly be supported by this Institution, to the effect that the present system was not satisfactory, that the present bill did not provide for sufficient amendments of it, and that the main basis of legislation should be on the broad principle that inventions were mainly a benefit to the state, and not alone to inventors as had been supposed.

Mr. W. Smith thought the point before the meeting was whether to go for certain amendments on the most flagrantly objectionable features of the bill, or whether to carry this resolution, which certainly did point to the bill being referred to a Select Committee. If the bill were referred to a Select Committee, he believed there would be no legislation on it for another ten years; that was one of the main difficulties. The attempts which the Lord Chancellor had made to educate the mind of the public to the desirability of *abolishing* the law of protection for invention had, he thought, done their work very mischievously. Inventors he was afraid were of that unfortunate class who were not easily stirred to activity, and who least of all understood their own interests, and were the least disposed to move in a direction likely to be useful. Such meetings as the present did a great deal of good by opening up the question, and the public, so far as inventors were concerned, had recently taken a much more lively interest in it. But if this bill were referred back to a Select Committtee, legislation could not be expected in less than ten years; and in the meantime the public interest would have flagged, and that which had now been done would have become stale and unprofitable. It would be a pity he thought to divide the meeting upon the first part of the resolution; and he thought the right thing to do would be to petition the House of Commons for

an alteration of the various objectionable features which were visible on the face of the Lord Chancellor's bill. The point was this: the body of the bill did not give satisfaction, and certain remedies were proposed; but to refer it back to a committee he thought would be a great mistake.

Sir Henry Cole said that, having taken some part more than twenty years ago in effecting a reform in the patent law, his conviction was that if the present law were effectually worked a new law would not be wanted at all. That was a very general opinion among patent agents, and even among some patent lawyers but not all; for lawyers got hold of this matter by tradition, and did not seem disposed to give it up if they could help it. Inventors generally complained, some with justice and others not quite with justice, that the present working of the patent law was too costly. If the present enormous revenue of the patent office—which was something fabulous, amounting to as much as £180,000 or £190,000 per annum—instead of being put into the exchequer and made a source of revenue which was never intended, were applied to making the patent law as good as possible and to providing efficient and responsible officers, it would be the right application of the money. Reports could then be obtained as to whether inventions were good or bad or indifferent—the reports to stand for what they were worth,—and a suitable museum obtained instead of having one which was a wretched abortion and a disgrace to the country. Not a single Lord Chancellor, who stood at the apex of this work, had ever cared for this museum. When Lord Selborne was asked whether he had been there, he said "I admit it is as bad as possible, but I know nothing about it." It was very little short of a constitutional fraud, he thought, to be taking £180,000 a year by the agency of this patent law, and doing nothing with it, doing nothing for the museum, nothing for specifications, nothing for the reporting of examiners; and then coming forward with a bill like this, which was full of antiquated absurdities. Admiral Selwyn had spoken about the absurdity of the Lord Chancellor being at the head of this business; a lawyer was not wanted at the head of the business, any more than a Lord Chancellor

was wanted at the head of the Charity Commission or the Civil Service Commission or the Board of Trade. It was not a question of law, but of common sense, in which men of business were most particularly interested. Inventors were the great parties interested in this matter, and it would be their own fault if they did not work this question until they got right principles adopted. The idea of having a Lord Chancellor, with half-a-dozen irresponsible unpaid and overworked officers to attend to this business, was one of those fallacies that had been exploded forty years ago by Jeremy Bentham and everybody else who had thought of the subject of administration. The whole notion of a lawyer to manage this business was altogether indefensible. People went to the law when they wanted the law; but when they wanted to know whether a man was making a true statement or not about an invention, or a comparatively intelligible statement, or to manage a museum, they did not want lawyers.

Then another thing was the appropriation of the fees. If desired the fees might be applied under proper rules to do all the good possible for the object in view; but to send them into the sea of the exchequer was in his opinion wholly indefensible. The Lord Chancellor had got impressed with the idea that a number of statesmen believed patents to be bad things. That conclusion however he thought had really not been generally arrived at, and the world did think invention was a useful thing and was worthy of protection; he did not want to discuss the rights of property, but he thought common sense would say thus much. There were some persons, he knew, who were sceptical on that point, and they had wrought a certain amount of conviction in the public mind; but he did not think society was quite ripe yet for getting rid of patents, and therefore they would be kept. The only question was how they should be administered rightly. On the face of it the present bill seemed to him to be a bad bill. He noticed one improvement over the existing law, which was the great seal was to be dispensed with, and the fee was to be paid by a stamp. That was however a very small matter, and it seemed to him about the only improvement in the bill. If the present law were honestly worked—if the government could be compelled to work it honestly, and were allowed

no peace till they did,—in his opinion there would be no want for any new law at all.

He was quite in favour of giving every inventor the right to get his registration as complete as it could be made, and of letting him have it at no greater cost than the cost of doing it. But he thought after an inventor had taken out his right, supposing it to last for three years, there was a great advantage in the process of settling whether it was worth his while to keep it or not by calling upon him to pay £10 or £20 or £50 at the end of three years. There was no doubt, if a man had perfected his invention after three years, some capitalist would then be found who was prepared to furnish the money. That was a good way he thought of getting rid of useless patents—testing them by the question, were they worth £50 or £100 at a certain period; whether the period should be longer or shorter he did not say.

Whether or not the present bill would get through, he supposed was very doubtful; if inventors and others raised a sufficient outcry against it, probably the Government would then give in. It was said that the Lord Chancellor had been talked to by some gentlemen who did not like patents and who found them in their way. But what could the Lord Chancellor know about patents as affecting mechanical or scientific inventions? He was not connected with these subjects; he was a profound lawyer, and when the law had to be interpreted he was the proper authority to go to; but when mechanical questions had to be interpreted, a scientific man ought to be applied to. The best plan he thought would be to go against the bill altogether.

Mr. H. A. Fletcher hoped the resolution would be passed unanimously, because he thought the bill before the House of Commons was so radically bad that it would be impossible to improve it. As the last speaker had said, the only advantage which inventors would get was that instead of having a great seal, several inches diameter and containing a couple of pounds of wax, there would be a stamp in its place. With regard to the cost of patents, to his mind the greatest grievance with which inventors had to contend under the present system was that of the stamp duties, of £50 at the end of

three years, and at the end of seven years £100. Many inventions could not be perfected and brought to a financial success in three years or even in seven years; therefore he thought the system of stamp duties pressed exceedingly hard, not only upon the working men but also upon another class—the small masters,—who were perhaps struggling to establish themselves in business with insufficient capital and in the face of great competition, and perhaps their only chance of doing so was to make some improvement for which they took out a patent. It did press hard upon men of that class if these stamp duties happened to become payable when times were bad, or when the demand for the particular article or invention that they had patented was not very great. No improvement in the patent laws could be satisfactory to inventors generally in which these stamp duties of £50 and £100 were retained. In their place he would have a system of small annual payments.

Mr. A. J. Mundella, M.P., understood the resolution to express dissatisfaction with the proposed measure before Parliament, and to request that it should be referred to a Select Committee; and the question under discussion was whether it was better to refer it to a Select Committee or not. That depended entirely upon whether the bill was capable of amendment or not. If the bill was incapable of amendment, the best thing was to move its rejection at once; but those who were in favour of that course should bear in mind that they were not strong enough to procure its rejection. It was of no use for them to move and carry that resolution, unless they could carry it in the House of Commons. The Government possessed a very large majority in that House; very few members knew anything about patents, and there was an immense dead weight of county members who would do exactly what they were told; and how could it be expected, by any process adopted at the present meeting, to procure the rejection of a measure that had passed through the House of Lords and come down to the House of Commons with the influence and recommendation of the Lord Chancellor? Notice had been given in the House by Mr. Dillwyn to move that the bill be read a second time "this day six months" whenever it came on.

That motion he should be glad to support, if he believed it was impossible to get the bill referred to a Select Committee; and if the Government refused to refer it to a Select Committee he would vote for its rejection. It was "better to bear the ills we have, than fly to others that we know not of." He was quite clear as to the object and scope of the proposed bill; these were very well described in a few words used last year by Mr. Siemens, who said that "In Prussia there was a system of examination with a bias against the patent altogether. It appeared to him that under the provisions of the present bill the examinations would approach more nearly to those of Prussia; the Commissioners appointed would be instructed to seek for an excuse to refuse the application, rather than to try to modify the application in such a way as to give the applicant the benefit of a patent." The bill was put forward by gentlemen who believed that patents were bad things and who desired to strangle them altogether; they found that public opinion was too strong for that, therefore they desired to minimise the evil (to use their own expression). This was what they had said pretty much in public, and this was why the bill had received such cordial assent from Lord Selborne, Lord Granville, and other opponents of patents; and this was why it would be welcomed in the House of Commons. He was quite sure that if this bill passed in its present shape the inventors in this country would be infinitely worse off than they were under the existing law. There was no comparison between the evils existing under the present law and those which would exist under the bill now before Parliament. Commissioners were proposed to be appointed to investigate questions of novelty and utility and to declare whether the patents applied for were frivolous or not; but when they were appointed for the express purpose of finding out that the patents applied for were frivolous and not novel, the inevitable result would be that the majority of applications must be rejected. He had heard it well remarked that Mr. Bessemer and some of the most important inventors of modern times would never have got patents under such an arrangement. There was no doubt a tendency in the minds of a number of statesmen to discourage patents and get rid of them altogether; he believed it

to be an infatuation, but the fact must be recognised. There was the present Lord Chancellor, the late Lord Chancellor, Lord Granville, and many other influential men among the peers; then there was Mr. Justice Grove, and Sir William Armstrong. He could quite understand Sir William Armstrong's position: his invention was a gun, and he could go to the Government and obtain a handsome reward for it, because it was an invention which only the Government could properly appreciate and reward; but suppose he invented a new spinning-jenny as Arkwright did, what chance would he have of getting from the Government a pecuniary reward, however meritorious his invention might be.

He would ask the meeting to be unanimous on this subject. It had been said that if this matter were referred to a Select Committee it might be ten years before any further legislation was obtained. But rather than have things as they were proposed to be made, they had better remain ten years as they were, simply deferring the time when inventors would be strangled; it was a case of prolonging existence. The bill he believed was capable of amendment, and if engineers and inventors generally would make up their minds as to what amendments were wanted, and would agree upon them and formulate their demands, and the matter were then referred to a Select Committee, in a fortnight or three weeks witnesses could be brought before that Committee to show the necessity for modifying the bill; he did not believe a Committee would report against the petitioners.

With regard to the litigation which arose from patents, there were two or three thousand patents a year that worked smoothly enough without any litigation whatever. He had himself been a patentee for twenty-five years, and his firm had had about twenty patents, and he was sure all their litigation would be covered by a very small amount indeed; there had been very little vexation and inconvenience, and that he believed was the experience of most patentees.

He believed a Select Committee would report in favour of inventors, but if inventors did not succeed in getting a report in their favour they would only be in the position they were in today;

and they could then fight in the House of Commons. But if they wanted to do anything effectual they must agree amongst themselves, formulate their demands, and place them before an intelligent Committee of the House of Commons. The resolution as it stood he believed was the best possible resolution.

Mr. CRAMPTON could not but notice what Mr. Mundella had said with regard to their having one common object. There appeared to have been several meetings acting independently. Such an operation certainly could not be carried through satisfactorily unless all who were interested could unite into one common centre from which to radiate their views and opinions. This question he thought should not be independently mooted by different bodies, but the most influential men should be induced to take the initiative; such a course he thought would tend to produce the best results.

The CHAIRMAN thanked Mr. Mundella on behalf of the meeting for his great kindness in attending on this occasion and so freely expressing his views, which had had a great effect upon himself, for he felt more strongly than he had done before that the right thing to do would be to be unanimous and to refer this matter to a Select Committee. There was no doubt as to the political difficulties which had been alluded to; the present Government had a large majority, and it appeared that, while they were conservative in many things, they went in for free trade in inventions.

The resolution was then put, and carried unanimously.

Mr. MUNDELLA said he would give notice that day in the House of Commons to move that the bill be referred to a Select Committee, and the probabilities were the Government would not object to a Select Committee. He might mention, to show what was going on, that there had been a commission to enquire into the state of the patent office, and he intended to ask for the papers. From what he could learn of the report of that commission—Mr. Lingen of the Treasury and the Master of the Rolls—it was to deprive inventors

of a great many facilities which they at present enjoyed; so that £180,000 or £200,000 a year was to be paid to the Treasury, and almost no consideration would be received in return.

A vote of thanks was passed to the Council of the Society of Arts for their kindness in allowing the Meeting to be held there; and to the Chairman for his conduct in the Chair.

The Meeting then terminated.

DYNAMOMETERS.

Spring Links.

Plate 28.

Fig. 1. *Front Elevation.*

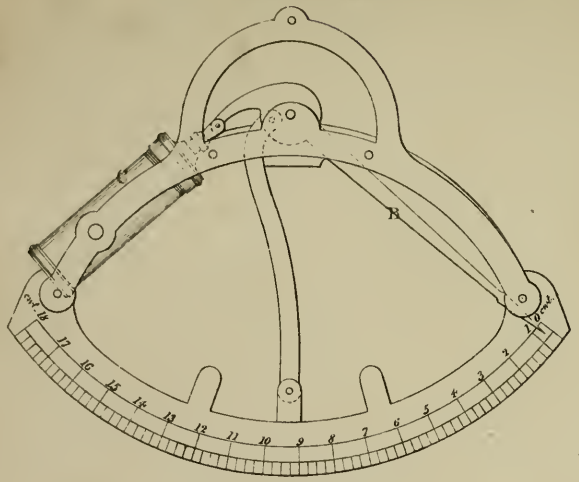


Fig. 2. *End Elevation.*

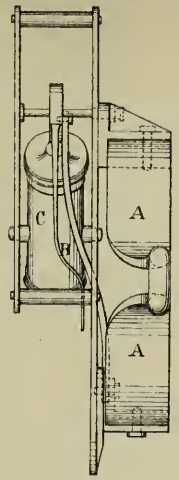


Fig. 3. *Back Elevation.*

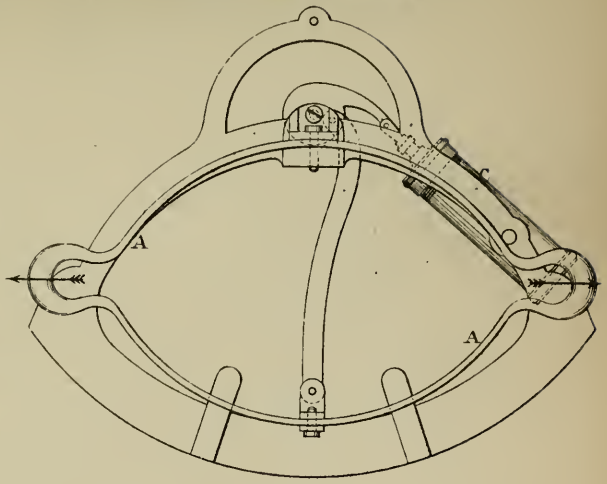
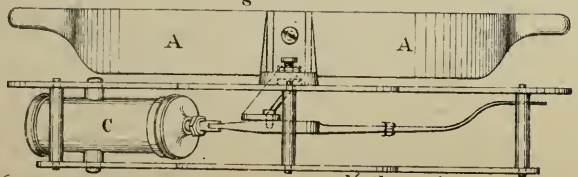


Fig. 4. *Plan.*



(*Proceedings Inst. M. E. 1876.*) *Scale* 1/6th.

0 3 6 9 12 Inches.

Fig. 5.

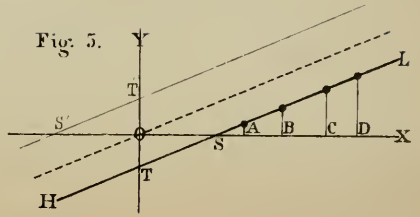
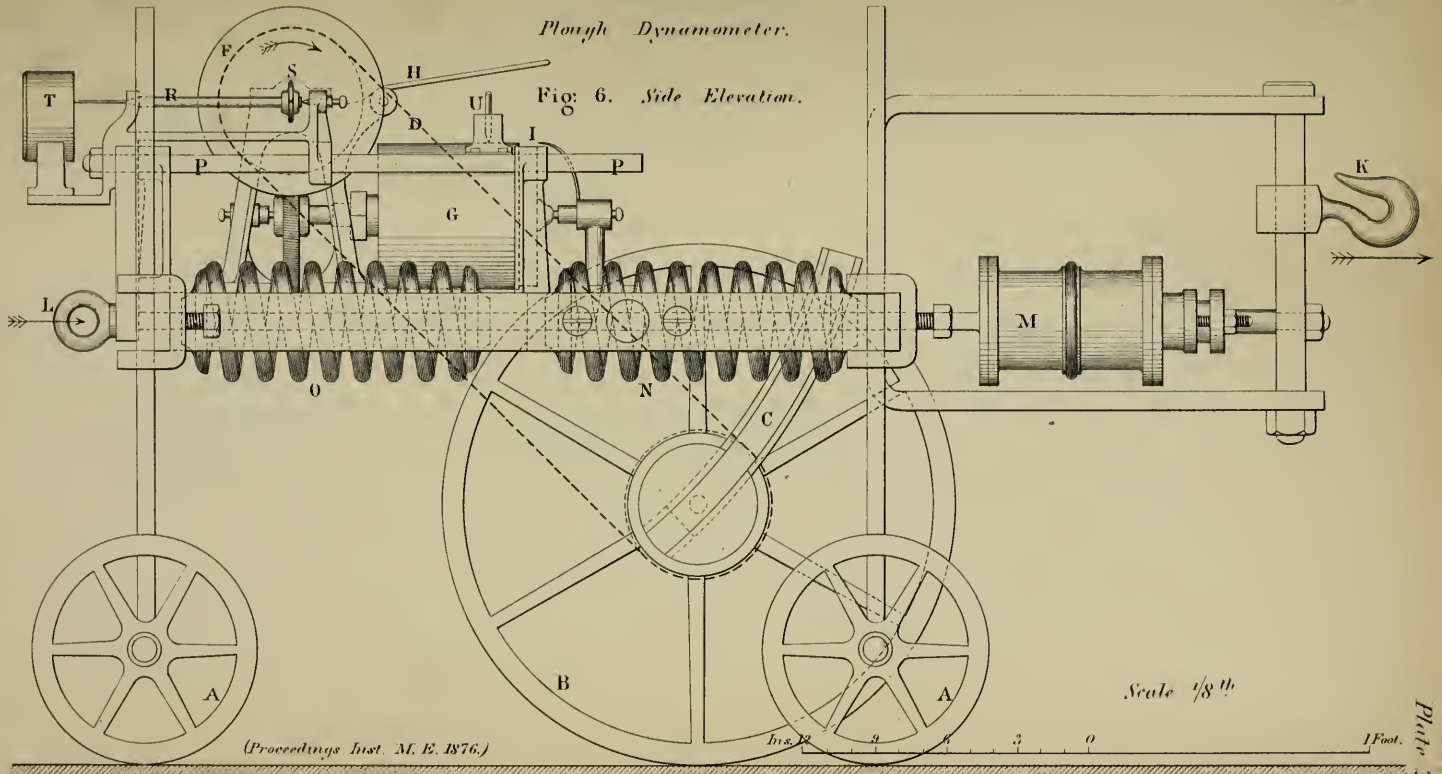


Plate 28.

Plough Dynamometer.

Fig: 6. *Side Elevation.*



(*Proceedings Inst. M. E. 1876.*)

Plate 29.

Plough Dynamometer.

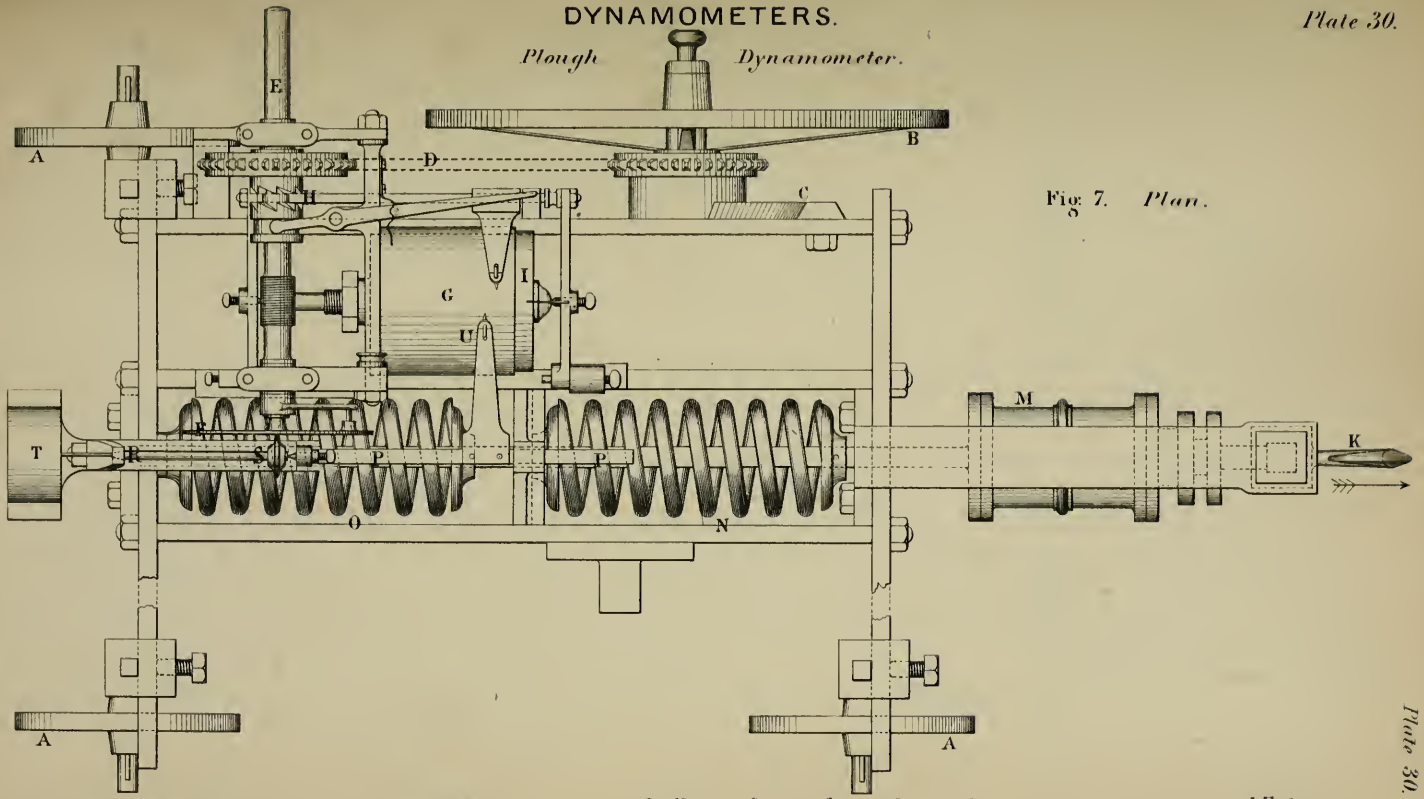


Fig. 7. *Plan.*

(Proceedings Inst. M.E. 1876.)

Scale 1/8th

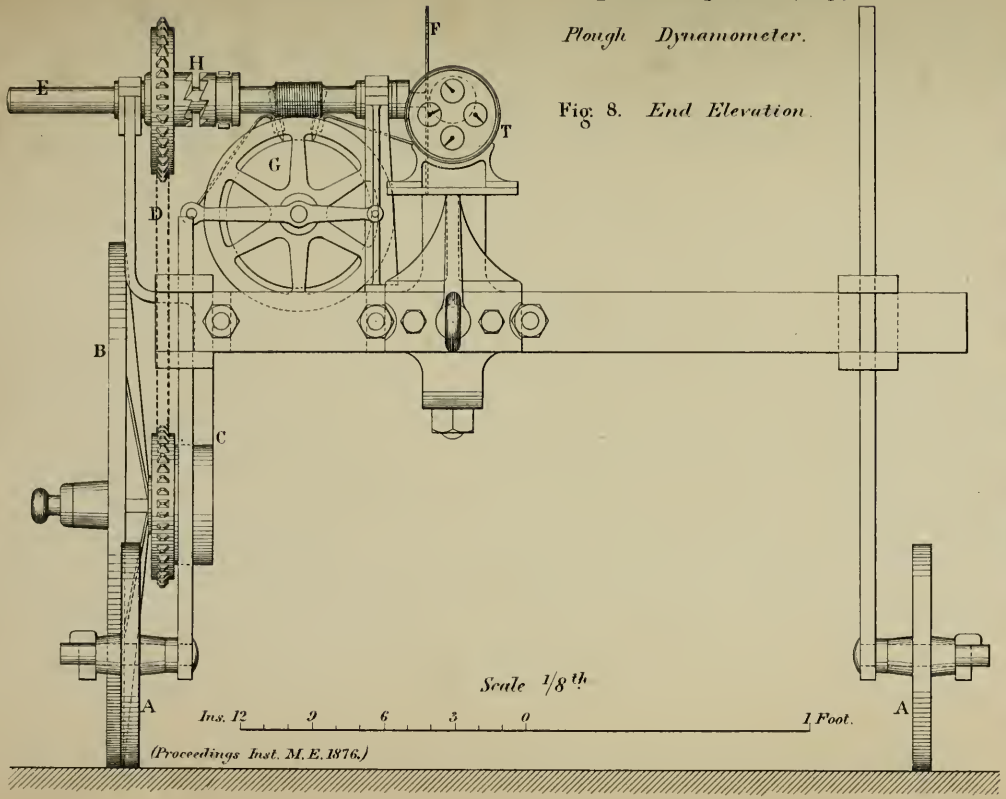
Ins. 12 9 6 3 0 1 Foot.

Plate 30.

DYNAMOMETERS.

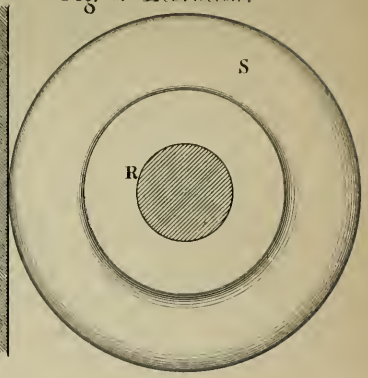
Plough Dynamometer.

Fig. 8. *End Elevation.*



(Proceedings Inst. M.E. 1876.)

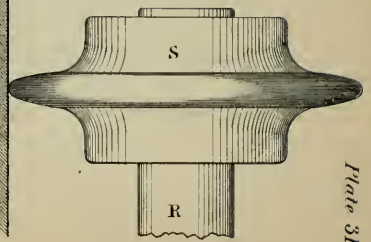
Fig. 9. *Elevation.*



Section of Disc F

Integrating Wheel.

Fig. 10. *Plan.*



Section of Disc F

Full size.

Plate 31.

DYNAMOMETERS.

Horse Dynamometer.

Plate 32.

Fig. 11. *Side Elevation.*

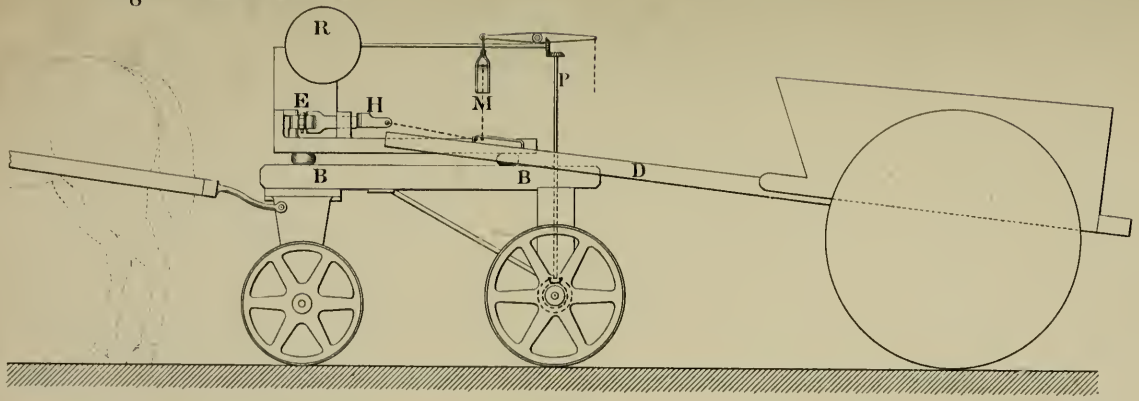


Fig. 12.
Front Elevation.

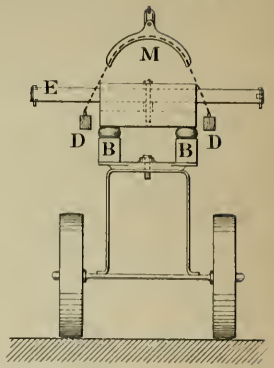
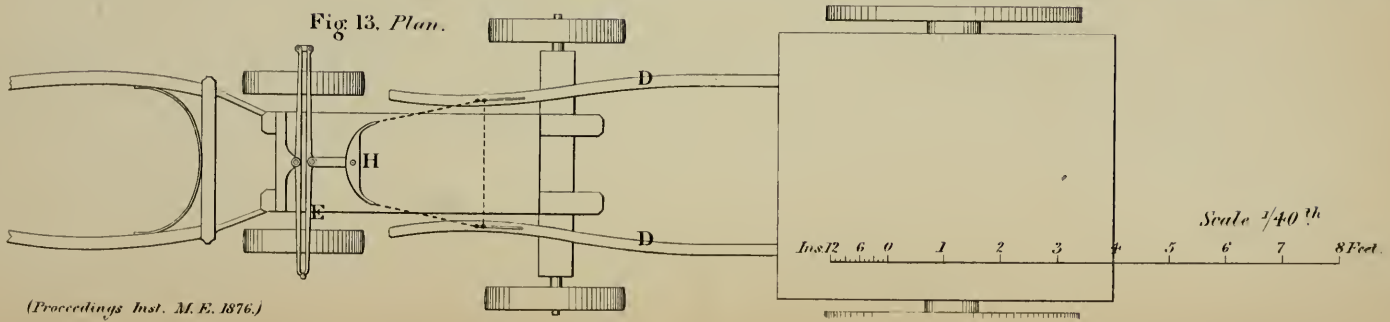


Fig. 13. *Plan.*



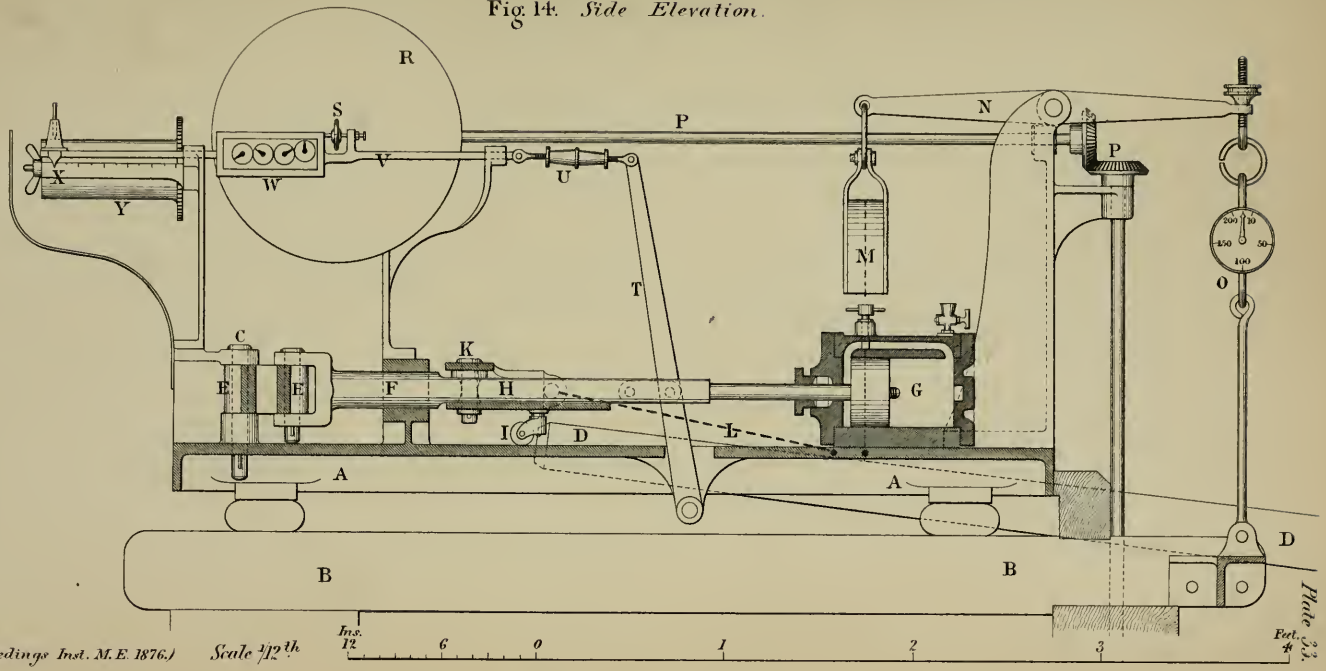
(Proceedings Inst. M. E. 1876.)

Plate 32.

DYNAMOMETERS.

Horse Dynamometer.

Fig. 14. *Side Elevation.*



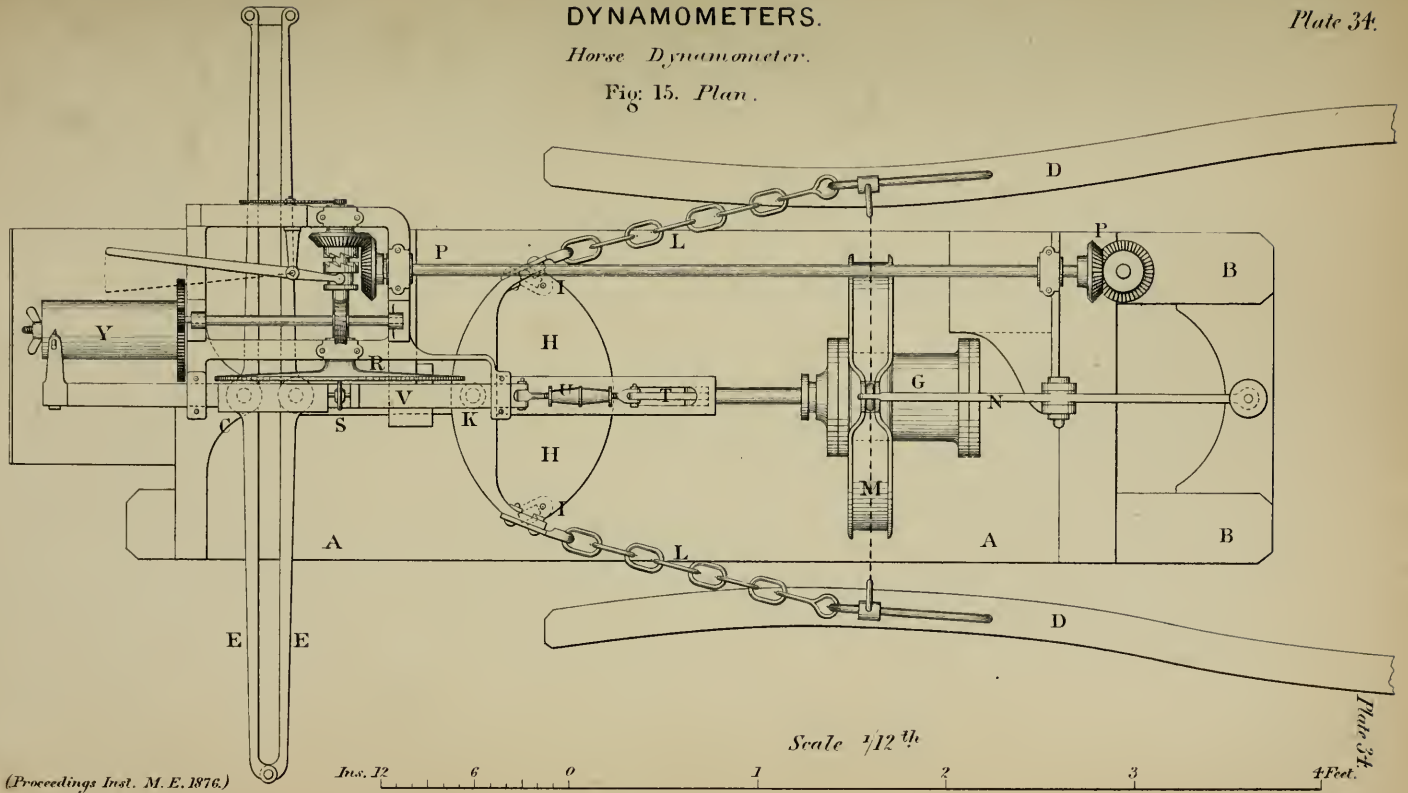
(Proceedings Inst. M.E. 1876.) Scale 1/12th

Plate 33.

DYNAMOMETERS.

Horse Dynamometer.

Fig. 15. *Plan.*



(Proceedings Inst. M. E. 1876.)

Plate 34.

100 Horse Power Friction Brake.

Fig. 16.
Side Elevation.

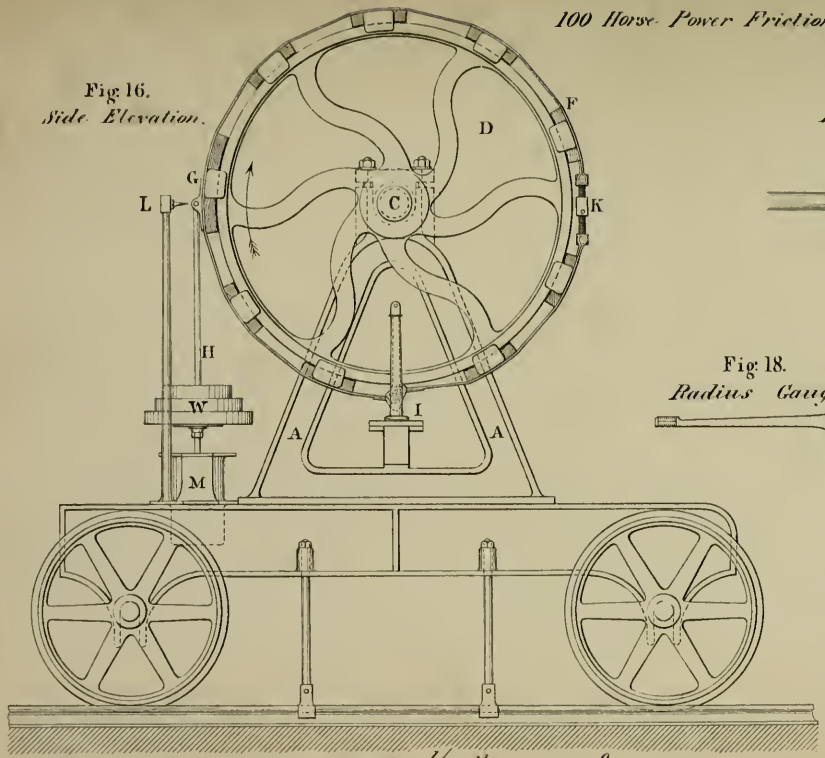


Fig. 17.
End Elevation.

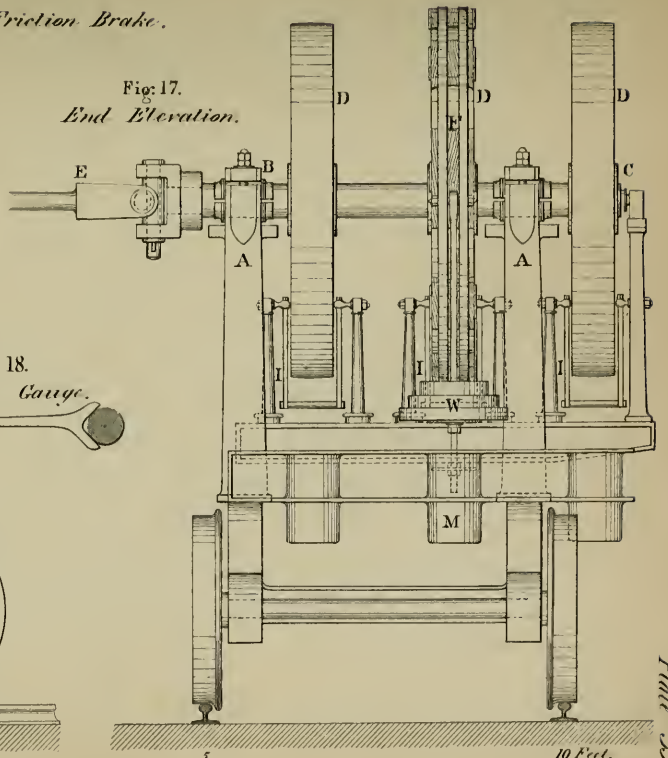
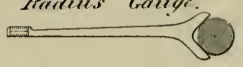


Fig. 18.
Radius Gauge.



(*Proceedings Inst. M. E. 1876.*) *Scale* 1/30th

0 5 10 Feet.

Plate 35.

100 *H.P. Friction Brake.*

Fig. 19.
Diagram of Pendulum when Slackening the brake strap.

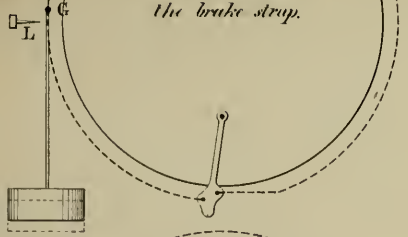
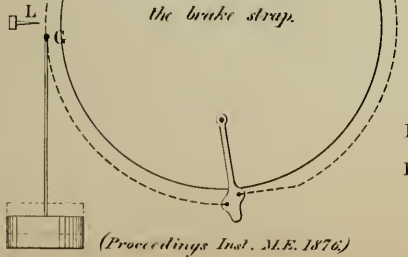
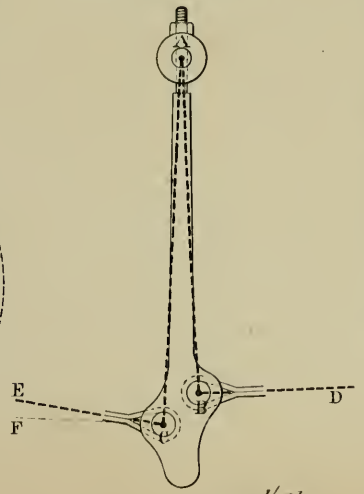


Fig. 20.
Diagram of Pendulum when Tightening the brake strap.



(*Proceedings Inst. M.E. 1876.*)

Fig. 21. *Pendulum.*



Scale 1/8th

20 *H.P. Rotary Dynamometer. Integrating Apparatus.*

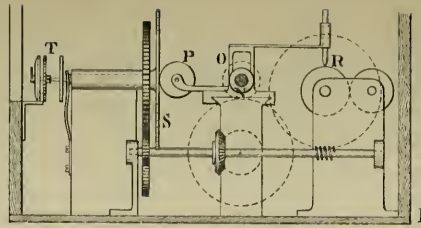


Fig. 22. *Side View.*

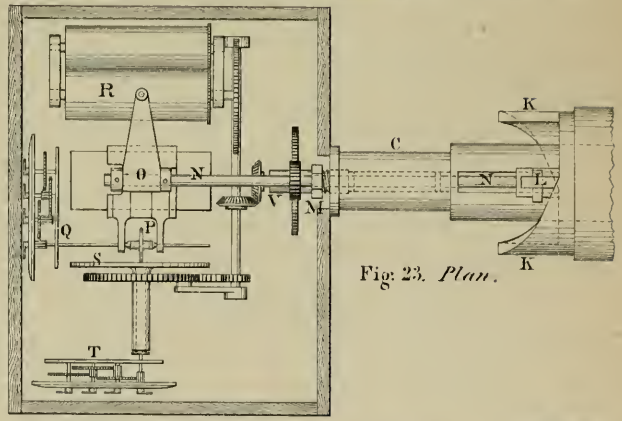


Fig. 23. *Plan.*

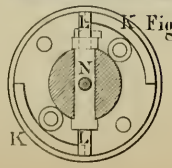
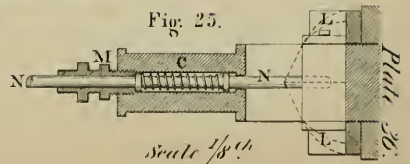


Fig. 24.

Fig. 25.



Scale 1/8th

20 H.P. Rotary Dynamometer.

Fig. 26. *Transverse Section.*

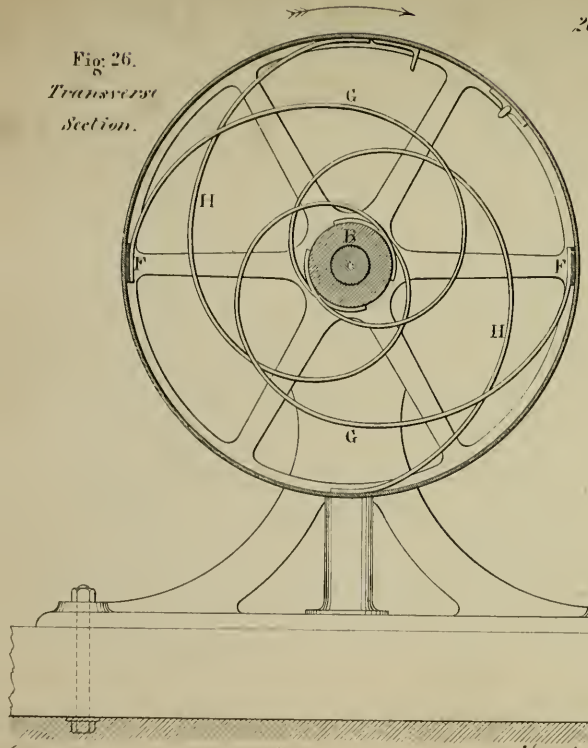


Fig. 27. *Longitudinal Section.*

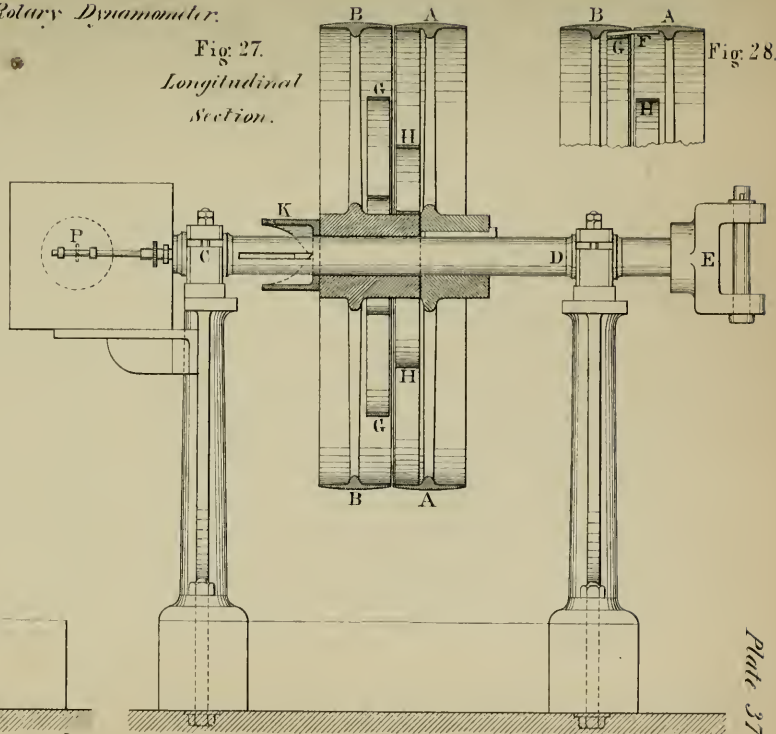


Fig. 28.

(Proceedings Inst. M.E. 1876.)

Scale 1/16 th

Ins. 12 6 0 1 2 3 Feet.

Plate 37.

Rotary Hand Dynamometer.

Fig. 29. *Transverse Section.*

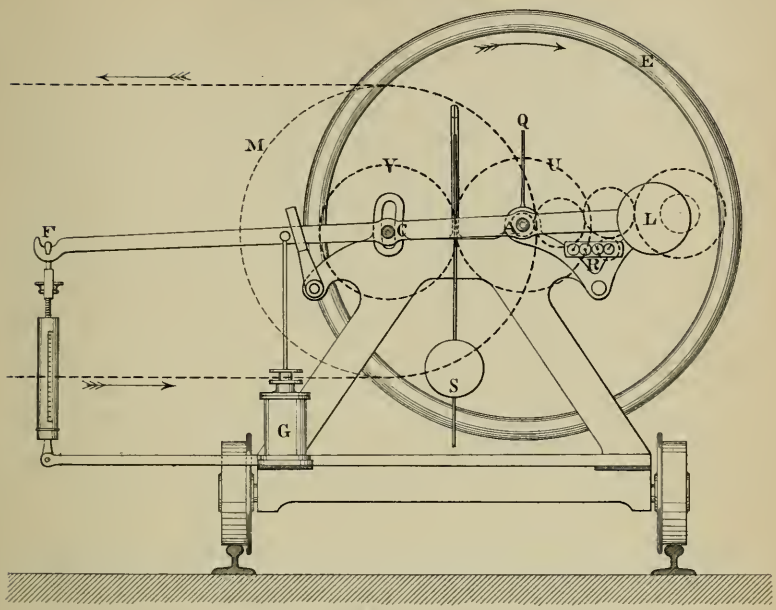
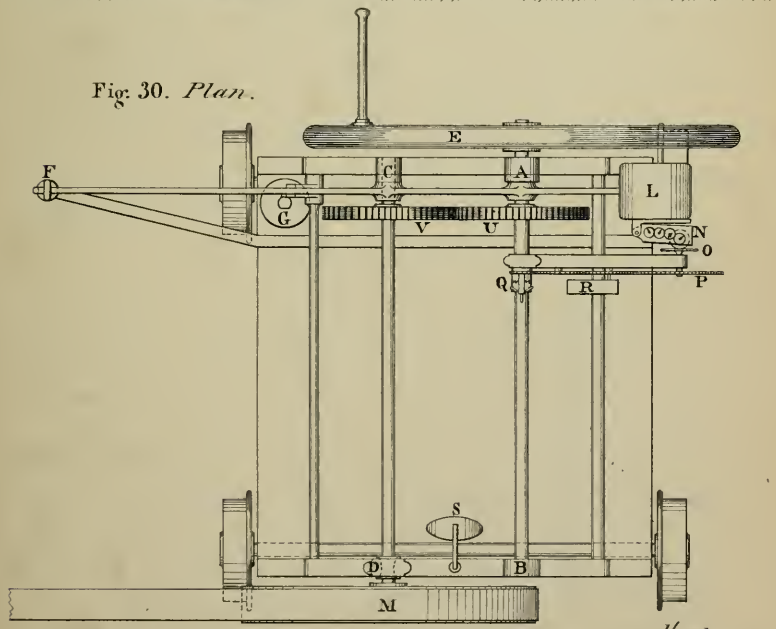


Fig. 30. *Plan.*



(Proceedings Inst. M. E. 1876.) *Scale 1/20th.*

Ins. 12 6 0 1 2 3 4 5 Feet.

Dead-Weight Rotary Dynamometer.

Fig. 32. *End Elevation.*

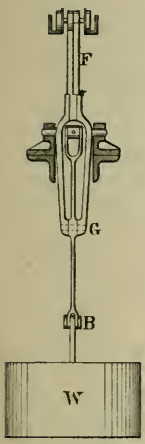


Fig. 31. *Side Elevation.*

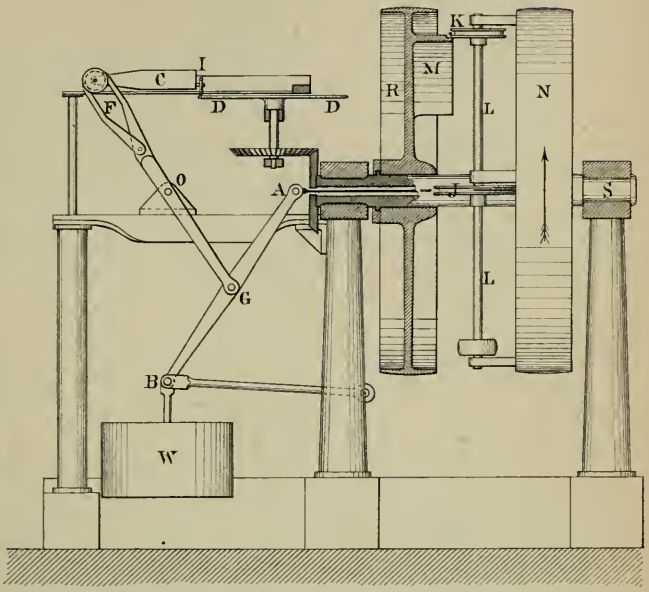


Fig. 34.

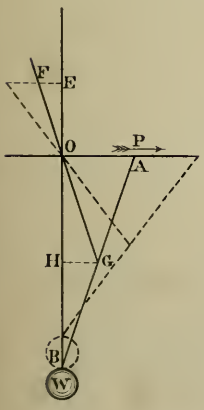
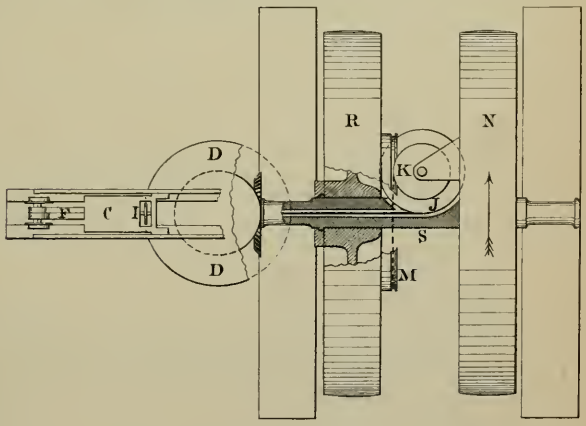


Fig. 33. *Plan.*



(Proceedings Inst. M.E. 1876.)

Walker and Warren, 1853.

Fig. 1.

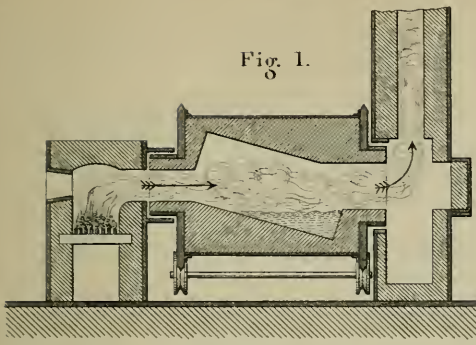
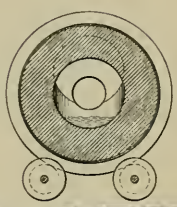


Fig. 2.



Maudslay, 1858.

Fig. 3.

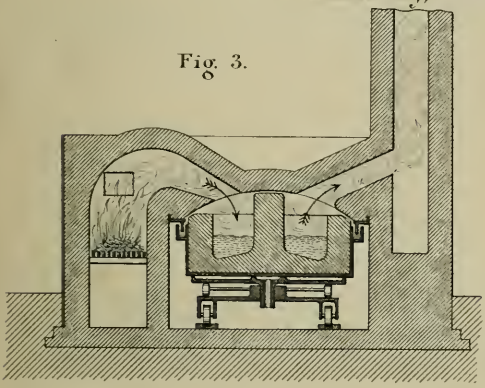


Fig. 4.

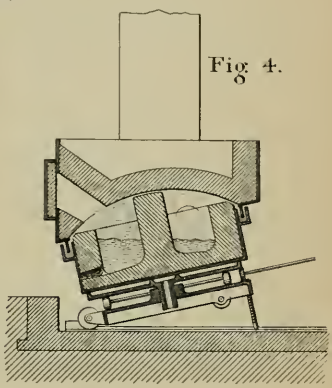
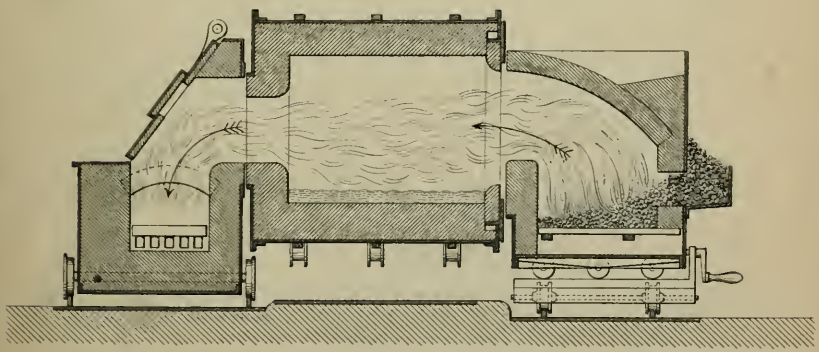


Fig. 5. *Tooth, 1861.*



(Proceedings Inst. M.E. 1876.)

Fig. 6. *Tooth, 1863.*

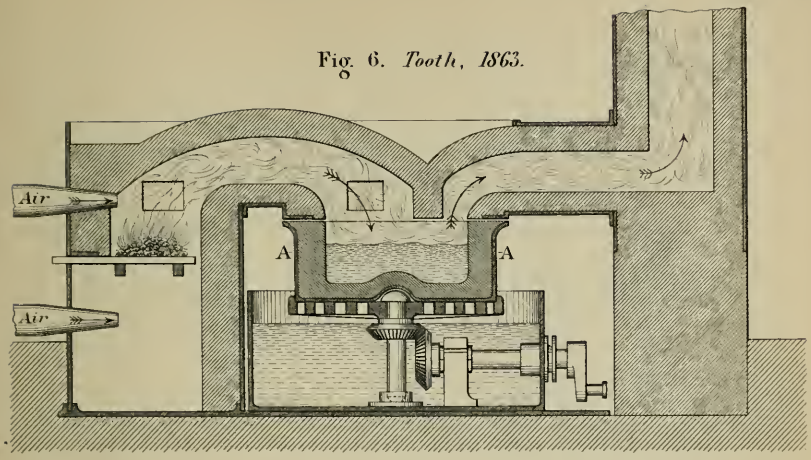


Fig. 9. *Sellers, 1871.*

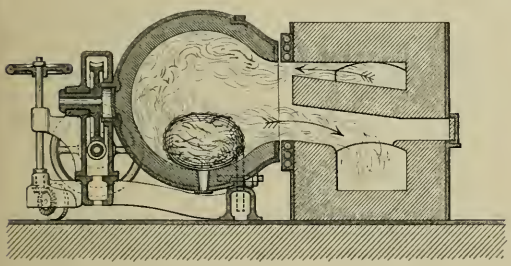


Fig. 7. *Tooth, 1863.*
Sectional Plan at AA

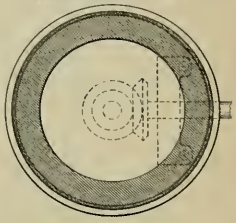
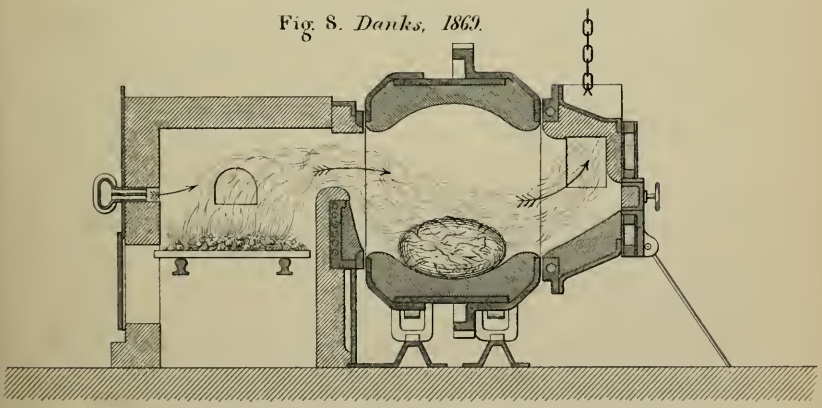


Fig. 8. *Danks, 1869.*



(*Proceedings Inst. M. E. 1876.*)

Fig. 10. *Siemens, 1871.*

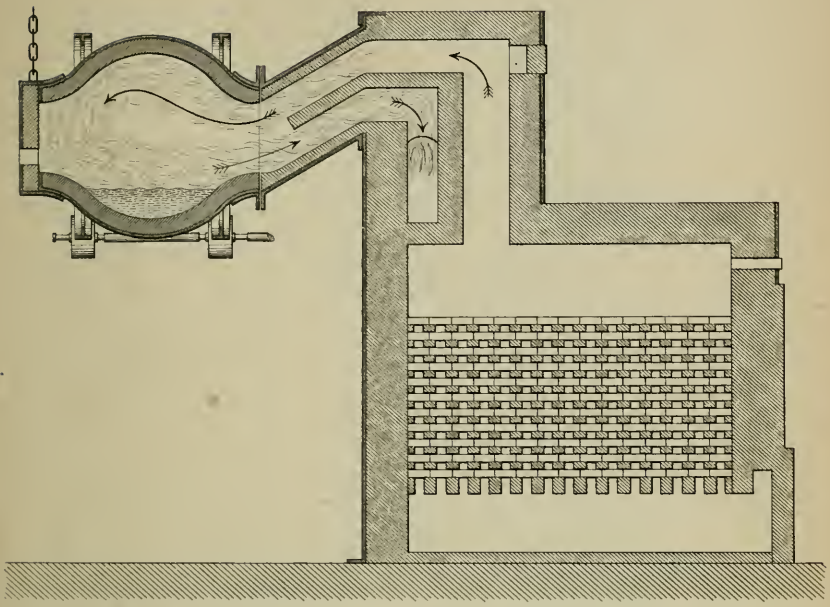
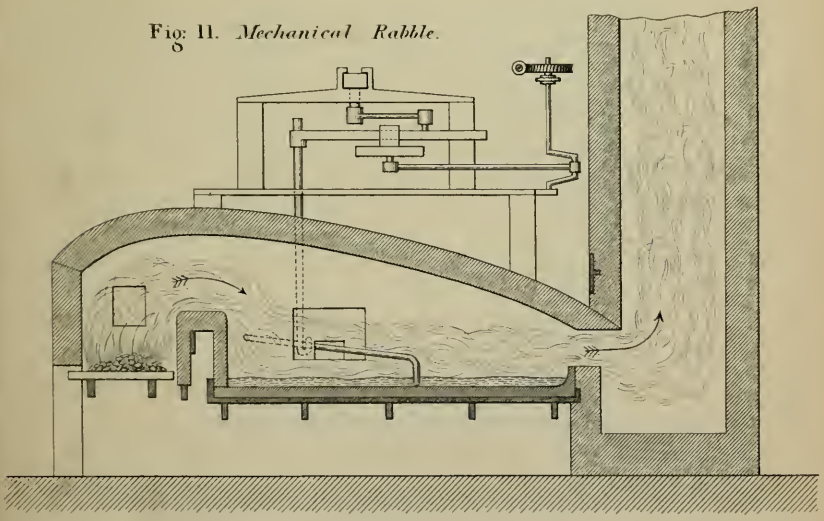


Fig. 11. *Mechanical Rabble.*



(Proceedings Inst. M. E. 1876.)

MECHANICAL PUDDLING.

Crampton's Rotary Dust-Fuel Furnace, 1872 and 1873.

Fig. 12. *Longitudinal Section.*

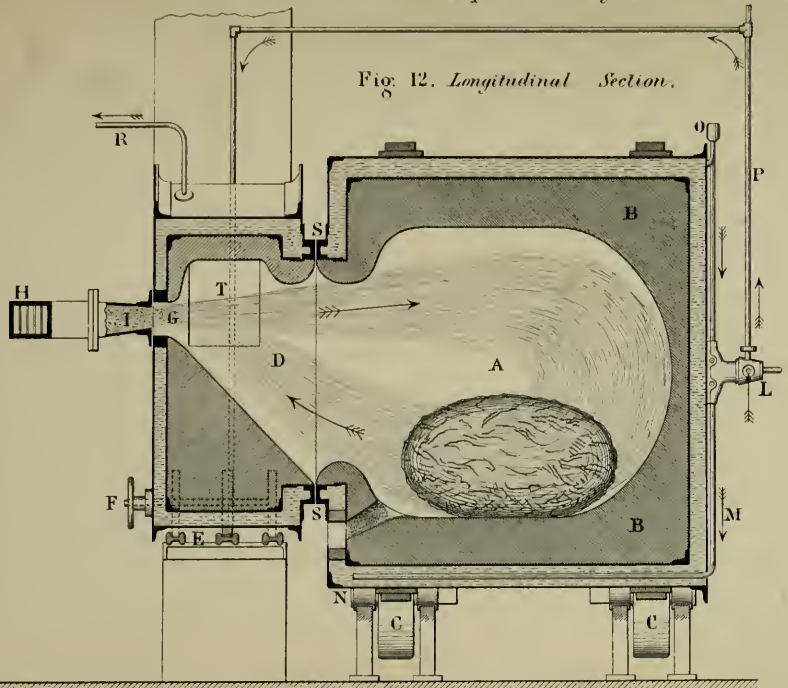
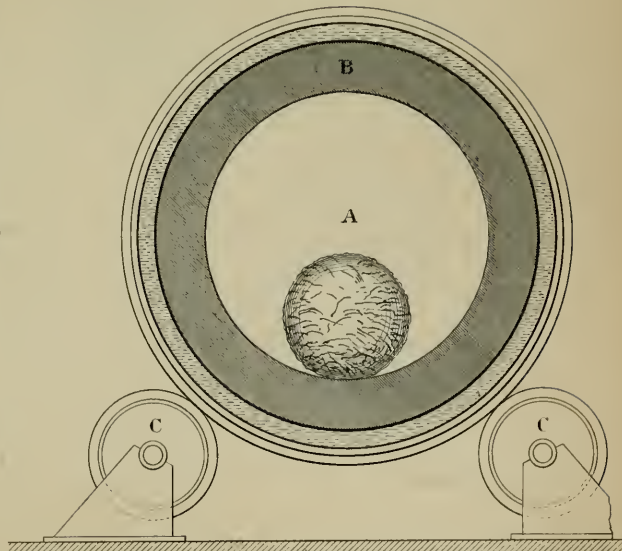


Fig. 13. *Transverse Section.*



(*Proceedings Inst. M. E. 1876.*)

Scale 1/36th

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Plate 43.

Crampton's Rotary Dust-Fuel Furnace, 1872 and 1873.

Dust-Fuel Feeding Apparatus.

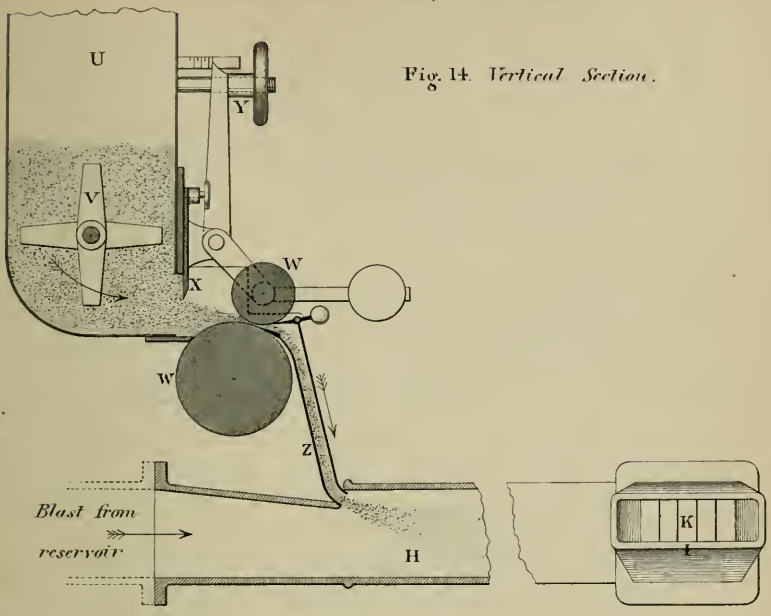
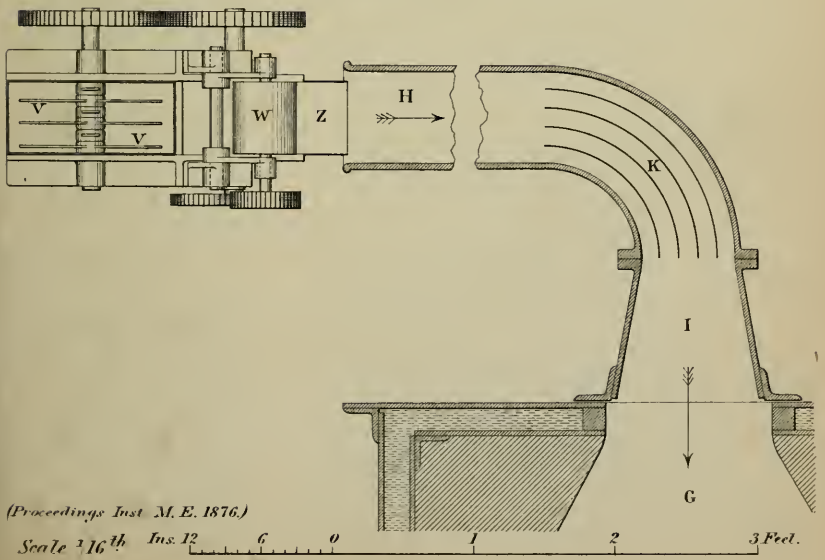


Fig. 14. *Vertical Section.*

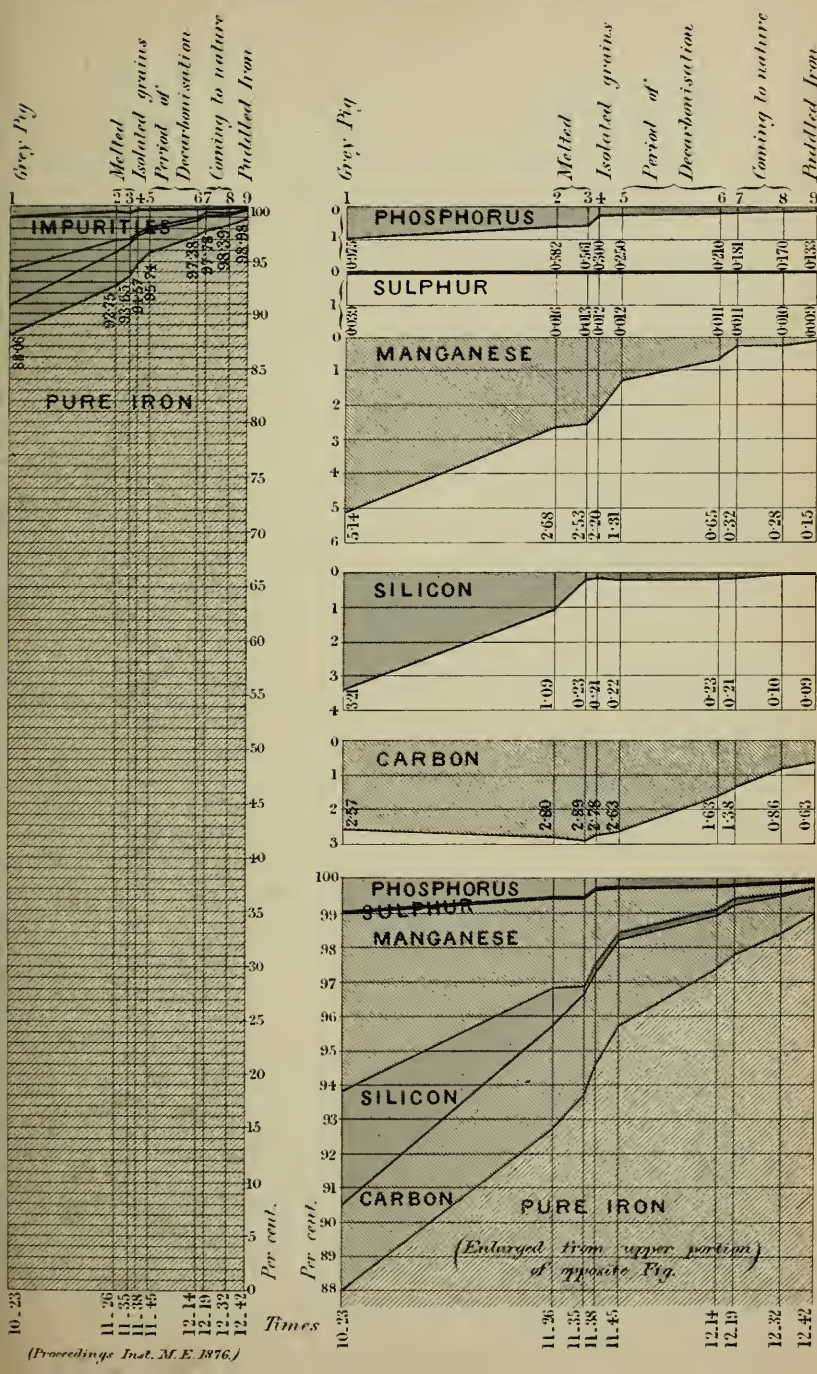
Fig. 15. *Sectional Plan.*



PUDDLING FURNACE.

Plate 45.

Analyses of Iron during Puddling in Ordinary Furnace.

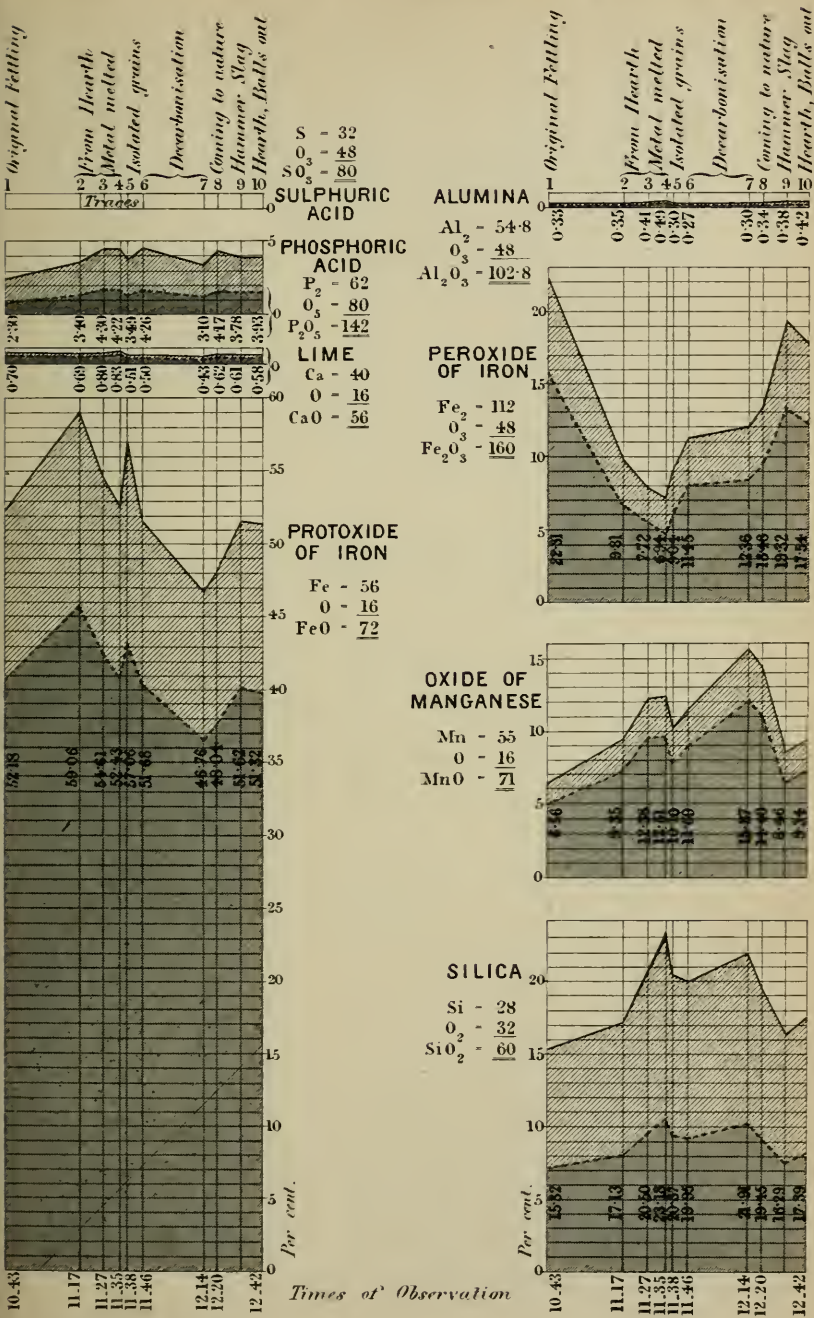


(Proceedings Inst. M.E. 1876.)

PUDDLING FURNACE.

Plate 46.

Analyses of Fettling during Puddling in Ordinary Furnace.



(Proceedings Inst. M.E. 1876.)

PROCEEDINGS.

JULY 1876.

The SUMMER MEETING of the Members was held in the Midland Institute lecture theatre, Birmingham, on Tuesday, 18th July, 1876; THOMAS HAWKSLEY, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

JOHN WILLIAM GRAY,	Birmingham.
THOMAS WILLIAM HIND,	Nottingham.
GEORGE ROBERT JEBB,	Birmingham.
WILLIAM MELLAND MANLOVE,	Chesterfield.
JOHN MATHER,	London.
WILLIAM MENZIES,	Newcastle-on-Tyne.
RICHARD HOBBS TAUNTON,	Birmingham.
WILLIAM HENRY OSBORNE TAYLOR,	Pontypool.
JOHN TURNEY,	Nottingham.
WILLIAM WHITELEY,	Huddersfield.

The PRESIDENT said that in consequence of a long absence he had not been able to prepare to his satisfaction for the present occasion the usual address delivered by the President according to previous custom. But there was another reason why he did not propose just now to enter upon the subject matter of that address—there was a great deal of work to occupy the present meeting, a great deal to

see, and much that would be of such an interesting character that he was sure it would be more desirable that he should defer his intended address to another occasion than occupy the time of the meeting by delivering it now. He proposed therefore to avail himself of an opportunity which would be more advantageous to the members, as well as more convenient for himself, to deliver a carefully written address, rather than trust the important subject on which he proposed to say a few words to the utterance of the moment. It would contain references to important statistics connected with a matter of engineering, which could not be well borne in mind or uttered orally without the risk of some mistake or misapprehension.

He had great regret in announcing the decease since the last meeting of two of the most valued members of the Institution. One was Mr. Robert Napier of Glasgow, a Past-President of the Institution, who was one of the most celebrated engineers connected with marine work, and who at the ripe age of eighty-five had departed this life. The other was Mr. Beyer, who was one of the principal locomotive engine makers, and who stood in relation to this Institution in the proud position of one of its founders. In both these cases he was sure the meeting would agree that it was desirable to concur in passing a vote of condolence with the families of the deceased members. The vote was passed accordingly.

The following paper was then read :—

ON DYNAMOMETERS, FRICTION BRAKES, AND OTHER TESTING APPARATUS BELONGING TO THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.

By Mr. WILLIAM E. RICH, of London.

The concurrence of the Summer Meetings of the Institution of Mechanical Engineers and the Royal Agricultural Society, at Birmingham this year, in the same week, affords a fitting opportunity for laying before this Institution a description of the most important instruments and testing apparatus belonging to the above Society; a valuable collection of apparatus, which the writer thinks well worth the attention of this Institution.

At starting he thinks it right to claim from his fellow Members a due recognition of the immense debt which engineers and agriculturists, all over the world, owe to the Royal Agricultural Society for the admirable series of engine and implement trials which it has carried on annually with so much spirit and perseverance for the last thirty years. No other public body has ever done so much, or spent so much, on trials of machinery of any kind; and it would be well if other societies or government departments would only consider the wonderful effects which these trials have had in improving agricultural machinery, and would try to emulate the Society in other branches of mechanical industry.

What was the portable engine thirty years ago?—and what is it now? when the city of Lincoln alone is said to turn out two thousand of them in one year; and two different firms can produce competing engines, which run a dead heat of over five hours, with a consumption of 2·88 lbs. of Welsh coal per actual brake horse power per hour. No one will deny that this degree of perfection is largely due to the publicity and thoroughness of the Society's trials; and one cannot but reflect on the numerous benefits which the English Admiralty authorities would confer on marine engineers and the

commerce of the world, if they occasionally made equally exhaustive and careful trials with marine engines of different types, and published the results in extenso, as the Agricultural Society invariably does.

The more important instruments belonging to the Society may be classed under three heads, viz. :—

1st—Traction Dynamometers, for measuring the draughts of implements and vehicles, drawn by horses or otherwise.

2nd—Friction Brakes, for absorbing the power developed by steam engines, and other prime movers, by uniform frictional resistances; and

3rd—Rotary Dynamometers, as they are commonly called, which register the amounts of power that must be transmitted to various machines from external sources, in order to work them.

Traction Dynamometers.—Spring Links.—The oldest draught testing instruments belonging to the Society are Spring Links or dial balances, analogous to the balances now made in such large numbers by Messrs. Salter, but inferior to their best productions. One of these instruments is illustrated in Figs. 1 to 4, Plate 28, and a specimen is exhibited to the meeting. The spring is an elongated flat steel link A A, through which the strain transmitted to any implement is passed by pulling on its ends in opposite directions, thus increasing its length and decreasing its width. The variation of shape moves the index hand B by means of levers, and the oscillations of the spring and this hand are reduced by means of an oil cylinder C.

It is apparent at once that the divisions on the dial cannot obey Hook's law of the distances travelled varying as the pulls, and it is necessary to determine all the divisions by actual experiment. Also the springs seem liable to twisting influences, probably dependent upon the exact points at the ends at which the pulls are applied, and this, combined with a little wear of the pins in the lever, seriously affects the uniformity of action of the index hand. The resistances of implements drawn by horses are very irregular and jerky, so that it is extremely difficult to read the mean draught

on an instrument such as this with any degree of accuracy; and for many years past these spring links have rarely been used, but have in general been superseded by integrating traction dynamometers.

The Plough Dynamometer.—The first of these instruments is exhibited to the meeting, and was made in the year 1856, more especially for testing ploughs, cultivators, and other field implements drawn by horses, and it has proved itself to be a very valuable instrument for such duties. It has been reproduced for the Imperial Museum Berlin, the Ballarat Agricultural Society, and the Chilian Exhibition Commissioners. It is illustrated in Figs. 6 to 8, Plates 29 to 31, and consists of a light low-lying wrought-iron frame, mounted on four wheels, three of these A A A being supported on axles adjustable vertically and horizontally with clamps on the frame, exactly as in wheel ploughs, while the fourth wheel B, which is larger, is adjustable on the arc of a circle C, and drives the speed mechanism by means of a pitch chain and wheels D. The object of the vertical adjustments of the wheels is to permit one or two wheels to run in a furrow of any depth, while the others run on the unploughed surface. Generally when in action the small wheel on the driving side is lifted up altogether, to ensure that the traversing wheel shall always preserve its contact and driving power. By means of the pitch chain, the shaft E with the large gunmetal disc F at one end of it, and the paper drum G worked by a worm and wheel from the shaft, are driven at speeds proportional to the actual speed of the implement as measured on the traversing wheel. They can however be disconnected at will by means of the clutch and handle H.

The paper drum is arranged to receive one sheet of paper, wound round it as in a steam-engine indicator, and a pencil attached to the frame is pressed against the paper by a spring, to draw a straight zero line on the paper as the drum revolves. On the end of the drum a distance index I is engaged, one revolution giving about 200 yards travel in the instruments for English use. The drum and this index can, if desired, be disconnected without stopping the rest of the working parts, by slacking back the screw

at the end of the drum. The several elements of the apparatus so far described all move with speeds proportioned to that of the instrument in travelling along the ground.

The horses employed for drawing the dynamometer are attached by whippletrees to the main frame and carriage at its front end K, and the implement to be tested is attached to the eye L at the back end of the drawbar. This drawbar is attached to the back end of the oil cylinder or dash pot M, and a piston and piston rod in this cylinder attached to the extreme front of the carriage assist in supporting it. The drawbar is further supported by the three cross frames of the carriage through which it passes; and two spiral springs N O embrace it, one N resting between the centre frame and the cheese-head which is pinned to the bar in front of it, and the second O is similarly placed in front of the rear frame.

From the drawbar at its back end rises a vertical crosshead, to which a horizontal guide bar P P is bolted. This bar slides through two of the cross frames, and across the face of the large disc F; and it is mounted with headstocks which support the ends of a delicately fitted shaft R, on which a small brass disc S is keyed or soldered, in such a position that when the instrument is unloaded it touches the large disc exactly at its centre. This small disc, generally about $1\frac{3}{4}$ in. diameter, and shown full size in Figs. 9 and 10, Plate 31, is called the integrating disc, and by means of its shaft, and a short piece of india-rubber tube forming a universal coupling, it works the small counter T at the back end of the bar; this counter is called the integrating counter. The bar P near its front end carries a pencil U in a light spring, which presses it against the surface of the paper drum. The large disc is pressed against the edge of the small one by means of a spring contained in the hollow shaft which carries it.

It will be seen that the revolutions made by the large disc in any time must be proportional to the distance traversed in that time, as measured by the traverse wheel which drives the disc. It is also apparent that the pull of any implement, applied to the drawbar will compress the springs to an extent proportioned to

the pull applied, and will move the small disc across the face of the large disc to the same extent. If the edge of the small disc is exactly touching the centre of the large disc when the springs are unloaded but not slack, the distance of the small disc from the centre of the large will also vary directly as the strain, and the velocity ratio of the discs will therefore vary in the same proportion.

It appears then that the number of revolutions of the small disc in any experiment will depend partly upon the distance travelled, as measured by the revolutions of the large disc which drives it, and partly upon the pull of the implement which draws it away from the centre of the large disc, and increases its revolutions per revolution of the large disc in direct proportion to the strain. It can be further shown that the number of revolutions of the small disc, multiplied by a constant co-efficient, is equal to the distance run, multiplied by the pull, that is in other words to the ft.-lbs. of work done. For let

P = pull of implement in lbs.

d = distance run in ft.

N = number of revolutions of large disc.

n = do. of small integrating disc, as recorded on counter. Then the distance run d can be represented as equal to AN, where A is a constant; and the pull P can be represented as equal to $B\frac{n}{N}$, where B is a constant, and $\frac{n}{N}$ is the velocity ratio of the small to the large disc. That is,

$$d = AN$$

$$P = B\frac{n}{N}$$

Therefore ft.-lbs. of work none $= d \times P = AN \times B\frac{n}{N} = ABn$.

A and B being both constants, put $C = AB$; then

$$d \times P = Cn,$$

and $C = \frac{d \times P}{n}$. Also the mean draught $P = \frac{Cn}{d}$.

When the set of springs and the instrument generally are in good adjustment, the constant C is the only co-efficient required for dealing with results obtained in experiments with it. Each set of springs has its own constant C, and though it is possible to calculate its value approximately when the range of the springs with any load

is known, it is always highly preferable to determine its value for any springs by direct experiment as soon as they are fitted, and occasionally afterwards, as sometimes they take a permanent set under strain, and the diameter of the small disc is liable to wear smaller, and it then becomes flattened transversely on its touching edge.

A pair of springs is best tested as follows. The weight of the draught bar, with its eye, crosshead, parallel bar, oil cylinder, and anything else moving with it, must first be ascertained, and the weight of the springs must also be determined. The dismantled parts must then be put together again, and the instrument being placed horizontally, the springs must be adjusted so that when there is no pull on the draught bar they are both held lightly between the cheese-heads at their ends, but perfectly free either from compression or slackness. All working parts should be examined to see that they can work freely, and they should be well oiled. Any oil in the oil cylinder should however be removed. Next the small disc must be adjusted till its edge touches the exact centre, both longitudinally and vertically, of the large disc. A practical check on this position is that the small disc should remain stationary when the large disc revolves.

To obviate the effects of friction of the drawbar and other parts in their bearings, it is well to push the bar and springs gently over in each direction, then release them and note the exact extreme positions which the integrating disc and pencil will assume after recoiling. The disc and pencil should then be carefully placed in the mean positions between these extremes, to determine their truly neutral points. If this is right or left of the large disc centre, the small disc with its bearings alone should be moved through the required distance to set it right on the large disc, without disturbing the draught bar and its belongings again.

The instrument must then be suspended front end uppermost to a crane or otherwise, and the draught bar being nearly vertical, known weights should be hung on to the draught eye. The effective weight W on the springs will then equal the known weight applied, together with the weight of the moving parts above determined, and half the weight of the springs.

The distance and integrating counters must then be set to zero, and the traversing wheel turned round till any determined distance, say 50 yards, is registered on the counter. The integrating counter register must then be noted, and the experiment should be repeated three or four times, shaking the draught bar up and down between each experiment. After this, two or three greater weights should be applied successively, and the instrument tested with each as before. The mean results of the experiments with each load should be tabulated. In a perfectly adjusted instrument, with perfect springs, C could readily be determined from any one set of such experiments, for if W = effective load,

d = distance in ft.,

and n = register of integrating counter,

the ft.-lbs. of work done $W d$ must $= C n$, and $C = \frac{Wd}{n}$ should be uniform whatever the load applied. In practice however C thus determined is never exactly the same for the different loads; but if the determinations do not differ much, it is better to take a mean of the several values of C derived from experiments with medium and high loads, which will give a more accurate coefficient than readings with very small loads.

Frequently however, in this and some other similar instruments, the values of C thus defined are so irregular that a correction is at once seen to be necessary. Really the figures read from the integrating counter in such cases do not vary as the pull multiplied by the distance, but every reading wants an addition or subtraction, varying with the distance only, to make them proportional to one another. The most frequent cause of this irregularity is the springs being under some compression when the small disc is centred on the large one, and then a quantity $k d$ (where k is a constant and d the distance in ft.) must be added to every reading before it is multiplied by C to get the total ft.-lbs. of work; and the reason for this is apparent, for the small disc will not begin to move from the centre of the large disc, and its counter will therefore not register anything, till the pull exceeds the initial compression of the springs, and successive readings for successive pulls cannot therefore be proportional to one another, till an addition is made to each,

depending on the smallest pull which begins to register by moving the disc.

A similar correction is necessary in many other instruments of the same type as this, and sometimes may be caused by friction of bearings or slackness of joints, when the small disc is adjusted to its zero; in that case generally the correction must be subtracted from instead of added to each reading. It should therefore be watched for in testing all such implements; and that being the case, the writer thinks it desirable to describe a ready method of detecting it graphically. He first noticed the necessity for this correction at some double-furrow plough trials at Caistor, Lincolnshire, in 1870, when testing the dynamometer in the field. In great perplexity to make successive tests accord with one another, he luckily had recourse to one of the engineer's best friends, a diagram, and at once found a straight line passing nearly through all the ordinates representing his tests, but considerably below the normal position.

The successive weights having been applied as described above, and means taken of the counter readings for given distances, those mean results should be divided by the distance in feet in each case, to get the index per foot run for each load. Let the ordinates A, B, C, D, on the diagram, Fig. 5, Plate 28, represent these counter readings per foot run, the corresponding abscissæ O A, O B, O C, O D, representing the corresponding loads on any convenient scale; draw the straight line H L which most nearly passes through all the points so obtained; then if this line also passes through O, as shown by the dotted line, the instrument is in perfect adjustment, and $C = \frac{W d}{n}$. Generally however, in this instrument, this line passes below O, intersecting the axes O X and O Y at S and T; then O S measured with the load scale will give the compressive strain on the springs when the small disc is at zero; and O T, on the same scale as the ordinates, gives the amount which must be added to each counter reading per foot run to give results proportional to one another, and this must be determined before C can be calculated. When the irregularity is due to looseness of joints, the line will generally cross O Y above O; then the correction must be similarly subtracted, instead of adding it.

Putting k for the quantity represented by O T, then

Total ft.-lbs. of work = $C \times$ corrected index; that is

$$W d = C (n \pm k d)$$

in which W represents any load, and $\frac{n}{d}$ (that is, index per ft. run) the corresponding ordinate to the line which most nearly cuts through all the ordinates determined by experiment. Therefore

$$C = \frac{W d}{n \pm k d}$$

and the mean draught P, which is the equivalent of W in all experiments with the springs in question, is

$$P = C \left(\frac{n}{d} \pm k\right)$$

In experiments on the draughts of ploughs &c. with this dynamometer, care must be taken that the traversing wheel B is always on the ground, and the instrument level both longitudinally and transversely, otherwise part of the weight of the implement is added to the direct component of draught. The draught chains between the dynamometer and the implement should also be as direct as possible. The adjustments for height are easily made by raising or lowering two of the wheels by means of the clamps, after raising the third off the ground altogether, and placing the traverse wheel at a convenient height considering the depth of the furrow.

The writer has found it desirable with this and other dynamometers, in testing each implement, to take two runs of about equal length in opposite directions, adjusting both counters to zero before the first run, and noting their registers after each run. The results are determined from the means of both runs. This precaution avoids risks of error from slight inclinations of ground, and gives immediately a ready check on clerical and instrumental errors, which are liable to creep in, unless specially guarded against, in the bustle and confusion of carrying out competitive trials in a crowd of interested spectators. It is desirable on such occasions to have an assistant at hand, to check the setting of the counters to zero, and the taking of all figures from them, as well as the tabulated records and all calculations from them.

All distances recorded should be taken from the distance scale or counter, and not from measurements in the field, as the traversing

wheel may alter its effective diameter by clogging, or might stop temporarily. The following is a simple and systematic sequence for tabulating results :—

Distance registered in ft.	d
Index registered	n
Index per ft. run	$\frac{n}{d}$
Do. corrected	$\frac{n}{d} \pm k$
Ft.-lbs. per ft. run, that is also mean draught in lbs. . .	$C(\frac{n}{d} \pm k)$

The paper cylinder with its belongings, referred to in the description of this instrument, enables diagrams of the strains and variations of strain to be taken during trials of implements. The paper being wound tight on the drum and secured, the zero pencil must be first adjusted to mark clearly and steadily; then the springs being unloaded, and the integrating disc at zero, the strain pencil must be adjusted to mark the cylinder on exactly the same line as the zero pencil.

When the instrument is started, a diagram is produced of which the zero line forms the base, the abscissæ denote distances on the same scale as the distance index, and the ordinates show the strains on a scale of loads determined from the springs. It is manifest that when a correction is necessary in the integration results, a similarly corrected base line should be drawn on the diagram produced. As a matter of fact, the writer has found the diagrams so produced to be so jagged in outline as to be comparatively valueless, as it would be impossible to determine the mean draught lines from them with any degree of precision; consequently in recent trials with this dynamometer he has seldom had recourse to the diagrams, which very much hinder experiments. The maximum strains recorded on the diagrams are sometimes valuable for showing the stresses which given implements should be strong enough to endure.

To an institution such as this it is well to notice the blemishes which have, of course, manifested themselves in this instrument, the first of its kind, during its useful life of twenty years, as many of them may easily be avoided in future integrating dynamometers.

In the first place, the wrought-iron frame is not stiff enough transversely, and twists slightly, occasionally increasing the friction of the draught bar and the parallel bar above it in their bearings. The number of bearings (six) which these two connected bars take in the frame and oil cylinder increases this tendency, and these bearings cannot be made slack, as any angular motion vertically of the lower bar moves the integrating disc, which is so far above it, horizontally on the large disc face. The arrangement of spiral springs in compression makes it almost a necessity that there shall be some initial strain on them, thus leading to the false zero adjustment and the more complicated formulæ and co-efficients described above.

The smallness of range of the springs and integrating disc (about 2 in.) is also undesirable, as the average compression should seldom exceed about one-half the maximum, and any slackness or imperfect adjustment anywhere may tell seriously on results, when the mean spring compression and disc travel is only about 1 inch.

The integrating disc requires a ready means of horizontal adjustment, and the oil cylinder has recently been noticed to have a defect common to the same detail in all these instruments, namely that it could not work when absolutely full of oil, in consequence of the smaller displacement at the piston-rod end of the cylinder. The rod should be carried through both ends of the cylinder, or some other arrangement made to obviate this.

The changing of springs is a tedious operation, as half of the working parts must be dismantled and re-adjusted afterwards, and the new springs must be tested, which is no easy matter in an implement trial field. Probably future editions of the instrument would be better with spiral springs in tension, and drawn directly from their centres.

The Horse Dynamometer (so called partly to distinguish it in name from other instruments, and also because it mechanically represents a harnessed cart horse in any implement or vehicle to be tested) was designed primarily for testing carts, wagons, and other wheeled vehicles having shafts, at the Bedford Meeting of the

Royal Agricultural Society in 1874. It was used again last year, at the Taunton Meeting, for testing mowing machines, and will again come into requisition next August for testing the reaping machines which are being selected for trial at the present Show. This instrument is shown in Figs. 11 to 15, Plates 32 to 34; it was designed by Mr. W. Anderson and the author in 1874, and was made at the Erith Iron Works. It is the most perfect integrating instrument belonging to the Society, every care having been taken to avoid sources of weakness and irregularity which had been noticed in the working of previous implements.

The general principle of this dynamometer is, that it shall occupy the same position as a powerful cart horse in any wheeled vehicle to be tested; that it shall draw the vehicle on any sinuous course by means of harness attached to the shafts in the usual way; and that in doing this it shall register the most important strains which a horse would have to exert in drawing it.

To determine in the first place the leading dimensions, a 16-hand cart horse was harnessed into an agricultural wagon, and subsequently into a two-wheeled cart, and his action in drawing these along straight and sinuous courses was narrowly watched. The carter was also closely questioned on the practice of harnessing horses into such vehicles, the proper height for shafts, back weight, &c. The adjustment of back weight to varying circumstances seems to be an important point with carters: they consider it desirable to have some weight always on the back of a cart horse, and for carting up hill they like to make it considerable by shifting the load, no doubt to add to the horse's gripping power. It was noticed that the shafts were materially wider than the horse's body, and that the draught chains expanded outwards from the attachments on the collar to the hooks on the shafts, and generally inclined downwards at the same time. In virtue of this arrangement it appeared that there was very little horizontal vibration of the shafts, and the horse was able to turn round moderate curves, without causing the shafts to rub at all sideways against his shoulders. The heights and positions horizontally of the collar chains, back saddle, breeching, &c., were measured, and the design was then proceeded with. The hind

wheels are placed at 4 ft. 8 in. apart between centres, the wheel-base being narrow so that vehicles which are to be tested on soft ground may not have to follow on beaten tracks previously made by the instrument. The front wheel-base is narrower still, the wheels being placed at 2 ft. 9 in. between centres, and carried in a wrought-iron locking frame, with a pair of ordinary wagon shafts for drawing it. Some vertical slackness on the locking pin is permitted in this frame, and this, combined with the narrow front wheel-base, ensures both the hind wheels always bearing when on uneven ground, this being a necessity, as one of them drives the speed-registering apparatus.

All the instrumental parts are self-contained on a small bed-plate A A, mounted upon a carriage frame B B of wood and iron, resting upon four broad and heavy cast-iron wheels, which add to its stability by lowering the centre of gravity. E is a pair of untempered steel draught springs, which are of uniform width, with planed edges, and are jointed with one accurately fitted pin at one end, and two such pins with a short link at the other end. This arrangement prevents any tendency to parallel-ruler motion, as would be the case if there were links at both ends; and at the same time permits each bar freely to assume its own shape and length, when under strain, which could not be the case if the springs were attached immediately to one another at both ends. The longitudinal section of the springs is approximately parabolic, the bases being at the centre eye in each case; their proportions were determined from statistics afforded by the late Professor Rankine, in his work on "Machinery and Millwork." There are three pairs of these springs, which are readily interchangeable, two pairs being 4 ft. long between end centres, and suited for maximum pulls of 600 and 1000 lbs., and the third pair 5 ft. long will work up to 1600 lbs. pull; one pair of these springs is exhibited to the meeting. The centre eye of the front spring is held by an accurately turned pin C, carried in a fork cast on the front end of the bed-plate; the eye of the other spring is similarly carried in a fork on the end of the turned draught bar, which is very stiff transversely, and is carried only in two bearings, namely F just behind the fork end, and the oil cylinder G at the back of the bed-plate.

Behind the bearing F the draught bar is flattened, and the draught plate H H is here jointed to it with washers above and below, to ensure great freedom of motion horizontally. This draught plate is a very important detail, and represents a horse's shoulders and collar; it is attached to the draught bar at its front end by the centre pin K, and the corners are supported on easy-running castors I I, which move freely in any direction on the top surface of the bed-plate. To these corners, beyond the castors, and considerably behind the centre pin, are attached the draught chains L L, which are hooked to the shafts D D of the vehicle that is to be tested. The height of these chain attachments, and their width apart on the draught plate, are very nearly identical with the height and width of the similar attachments on the collar hames of a 16-hand horse; and in virtue of this arrangement the dynamometer will draw a vehicle behind it round a considerable bend, always keeping both draught chains strained, and inclining the vehicle to follow in its track, without bearing materially against the inside of either of its shafts. The shafts really seem to float horizontally, rarely touching the sides of the instrument, and the tendency of the draught plate is always to right itself as soon as possible, like a stable floating body, whenever it is moved from its central position. The castors eliminate all vertical components of pull, so that only the direct horizontal components which are effective for doing work are communicated to the springs.

Above the oil cylinder G a wrought-iron chain saddle M, representing that carried by a horse in cart harness, is suspended from one end of the lever N, the other end of which is held by a Salter's balance O at the rear of the carriage. Over the saddle the ordinary shaft chains are passed, and the shafts being adjusted to their proper height by means of it, the weight carried on the saddle in any experiment can be read off readily on the dial referred to. Breeching chains are attached to the side frames, for restraining implements behind the instrument, when going down hill. At the rear end of the carriage, arrangements are made for testing any pair of springs readily in the field by means of a long-ended bell-crank lever, the short arm of which can be linked when necessary to

the back end of the draught bar, while to the long horizontal arm known weights are suspended at its outer end.

The integrating and registering apparatus are similar in principle to those in the plough dynamometer previously described; important improvements have however been made in the details. The distance counter and large disc R are worked by means of bevil gear and shafts P P from the hind shaft of the carriage, which is keyed into one travelling wheel, while the other runs loosely upon it; a clutch and handle serve to disconnect or connect the gear readily. The motion of the draught bar is trebled on to the integrating disc S by means of the lever T, which has its fulcrum self-contained on the bed-plate, and at its upper end is connected by the link U to a small gunmetal sliding frame V, which rests in two easy fitting bearings, and contains in itself the integrating disc S, with its shaft and a simple and easily read counter W worked by it, for recording the number of revolutions of the disc. The front end of the slide also, beyond its bearing, carries a pointer X for indicating to an observer the variations of draught and the maximum draught on a clearly figured scale of loads. The distance register is kept on an equally clear counter behind the large disc, and worked by toothed wheels off the driving shaft.

The maximum range of motion of the slide and integrating disc is in this instrument 8 in., and the disc can always be adjusted to the centre of the large one by means of the right-and-left-handed screws and nut on the link U. In this instrument too there is extremely little longitudinal friction either in the draught bar or slide, each of which is carried in two bearings only, which cannot twist relatively to one another. The springs also will always adjust themselves exactly to a passive position when unloaded, if the draught bar is slightly shaken by taps of a mallet on the side of it. This does away with all necessity for the complicated formulæ and corrections of readings, necessary with the plough dynamometer. Any pair of springs can be introduced, adjusted, and tested in a very short space of time; and the formula for the co-efficient with any pair of springs, $C = \frac{W d}{n}$, is found always to be approximately uniform, whatever

the effective load on the draught bar. Really *C* should increase very slightly when the springs are at their maximum range and curvature, but the irregularity is so small as to be inappreciable. The most important blemish which the writer recognises in this instrument is the oil cylinder, which, as in the plough dynamometer, has different displacements at its two ends; but this defect can easily be obviated now it is seen, and really in practice it has not been found necessary to fill the cylinder completely with oil, the range and inertia of the springs and other working parts apparently assisting to absorb most of the violent shocks brought upon them. Bosses and other provisions have been made on the front end of the instrument frame for adding a paper cylinder Y at any time, for taking diagrams with a pencil attached to the front end of the counter slide X; but up to the present time this has not been required.

When mowing and reaping machines are to be tested, a very narrow wheel-base is essential, as otherwise the standing crop would be injured, so the hind wheels are then replaced by a smaller pair, fixed at the same width apart as the front wheels; then also a horizontal bar at the rear end of the carriage supports the pole of the mowing machine, which projects under the carriage; and the side thrust of the pole can be read off, on a horizontal Salter's balance suitably attached to the carriage there. Then too a long iron whippletree bar is generally bolted across the draught plate, and the implements are drawn by long chains from the ends of the whippletrees.

At various times other draught-testing instruments have been arranged for the Society's trials, and notably among these were a hydraulic cylinder for testing pulls on steam-plough ropes, and an elaborate integrating dynamometer for a similar purpose. These instruments however did not give good results, and have therefore been discarded; and in the last steam-plough trials at Wolverhampton, in 1871, the total expenditure of work in ft.-lbs. per lb. weight of earth moved was determined approximately from indicator diagrams taken from the engine cylinders.

The Friction Brake Dynamometer, which absorbs the available energy of any prime mover by the friction of a strap on a pulley, and measures its amount at the same time, was invented by M. Prony; but the instruments belonging to the Society possess important modifications and improvements, which were introduced by Mr. C. E. Amos, and the late Mr. Appold, who as an amateur engineer always took great interest in the Agricultural Society's trials and testing instruments. In its present shape this instrument is by far the simplest type of dynamometer, and at the same time the most delicately accurate in its testing powers.

Three of these instruments were made for the Society in the years 1848, 1852, and 1854 respectively, all being of one size, and suited for a maximum of about 20 H. P., at 120 rev. per min. Originally each of them was mounted with one driving pulley, for receiving the power from the engine by means of a belt, and one brake pulley on the same shaft, for absorbing the power; but latterly two of them have been altered to drive with universal coupling shafts, direct from the engine crank shafts, and the belt pulleys have consequently been removed. The reason for this change is obvious, as the tension of a belt on both sides of the pulley, as formerly arranged, absorbed additional power in journal friction, and this loss was proportional to the tightness of the belt. The slipping of the belt, both by apparent sliding on the pulley and also from the difference of elasticity at its tight and slack sides, caused other irregularities which it was impossible to account for in recording results.

The 100 H. P. Friction Brake, which is the largest belonging to the Society, is illustrated in Figs. 16 to 21, Plates 35 and 36. It is on exactly the same principle as those above referred to, but much larger, having three brake pulleys on the same shaft, instead of one only, as in the smaller ones. It was made in 1871, for testing the largest ploughing and traction engines which were presented for trial at Wolverhampton in that year; and as Messrs. John Fowler and Co. had entered 20 H. P. engines, one of which actually worked up to 143 Ind. H. P. during short intervals in the plough fields, it was thought prudent to proportion the brake for a maximum of 100 H. P., at 100 rev. per min.

The instrument consists primarily of a cast-iron carriage and A frames A A, supported on wheels and axles, so as to be suited for running on rails in a long trial shed, opposite to which the several engines to be tested should be parked. Two well-fitted 5 in. bearings on the A frames carry the main shaft B C, on which three brake pulleys D D D, each 5 ft. diameter and 7 in. wide, are keyed, two of these being situated between the bearings, and the third on an extension of the shaft beyond them at C. To the end of the shaft at B a universal coupling shaft E is keyed. Any engine to be tested adjusts its crank shaft as nearly as possible to the same height and direction as the brake shaft, and then couples on to the universal coupling shaft with similar fork couplings, one of the forks being arranged to slide on the shaft E so as to adjust the length exactly, and avoid risks of end friction on any of the journal collars of either engine or brake. Each of the three brake pulleys D constitutes a complete brake in itself, and for moderate powers it is sometimes desirable to run with only one or two of them at work, the straps in that case being removed from the others. The brake also can be driven by a belt over one of these pulleys, if it is inconvenient to use the universal coupling shaft.

Looking at the side elevation of the instrument, Fig. 16, at any brake pulley, D is the pulley, F is a pair of straps of strong hoop iron passed round the pulley and screwed down to nine wood blocks, which are fitted to the slightly rounded outside rim of the pulley. Gunmetal side guides are screwed to the sides of the blocks to keep them in position laterally. On one side G an eye or joint is formed in the straps, and to this joint the testing weights W are suspended by means of a rod H. On the opposite side of the pulley the straps are cut, and connected again by means of the right-and-left-hand screw K, for adjusting the degree of tightness by hand.

At its lowest point the strap is severed again, and the ends are connected by pins to a pendulum I, sometimes called the differential lever. This connection is an ingenious mechanical contrivance, very simple in its details and easy to understand. Its object is to maintain a uniform frictional resistance on the brake by keeping

the joint G of attachment of the weight at a constant level, and this it does with extreme delicacy in the following manner. The pendulum, shown enlarged in Fig. 21, Plate 36, consists of two links suspended from joints on standards at each side of the pulley. Their length may be adjusted by nuts at their top ends, and by means of the joints in the standards they are free to move through angles of moderate extent on each side of their vertical position. The first essential with this pendulum is that its length shall be less than the radius of the brake pulley, and the second is that the ends of the strap on the weight side of the brake shall be jointed to it at a lower point or greater radius from its centre of suspension than the strap ends on the opposite side. A pointer on a standard L marks the proper position for the joint G, and the effect of the pendulum regulating apparatus is that if from any cause the friction of the brake blocks increases, and lifts the joint G above the pointer L, as shown in the diagram Fig. 19, thus circling the whole strap slightly round the pulley, the pendulum will incline towards the weight and slacken the strap in that direction to a greater extent than it tightens it in the opposite direction, in proportion as the radius of the one joint is greater than that of the other. The result is that G will return nearly to L, and if from continued actions of this kind it should move materially from this its normal position, the strap must be slackened by the hand-screw K, till G returns to L. A similar but directly opposite action takes place if G falls below L, from the strap being too slack, as shown in the diagram Fig. 20. The weight rod H carries at its bottom end a disc, which is a very easy fit in an open-topped cylinder or dash pot M, which is filled with water when the brake is in use. The weights W are of different sizes, and are slipped on to the rod above a disc, which is screwed to it for supporting them at such a level as to be well above the top of the dash pot, when the instrument is in use; but so that they can rest on the top flange of the dash pot, when the brake is at rest, without pushing the pendulum very far over in the opposite direction.

The revolutions of the brake are registered on a counter, placed on a standard opposite the end C of the shaft, and connected or disconnected at will by means of a handle and driving pins on the shaft and counter. Platforms are laid round the carriage for the convenience of the attendants, one of whom must always stand by the adjusting screws K, and alter them when necessary to keep the joints G opposite the pointers L, while another looks after the lubrication and cooling of the straps and pulleys with water services. The usual lubricants used are tallow and blacklead, introduced in lumps between the wood blocks, with a little oil occasionally from lubricators suspended above the pulleys. Water cans, with cocks, are also placed above the pulleys for the water-cooling services, the supply to the cans being usually kept up by a small hose when there are conveniences for so doing.

A forked steel gauge, shown in Fig. 18, Plate 35, is provided for measuring the exact radius of the joint G, at which the weights are suspended. To facilitate this measurement, the joint pin G is turned down to sharp points at its ends, and the mean distance of these points on either side of the pulley from the shaft centre are taken by pressing the fork of the gauge against the shaft and reading off the figures on a scale at the other end of it. The gauge has also engraved upon it a scale of the circumferences of the circles corresponding to the radii of the joint G, and it is usually more convenient to read off this scale. The brakes were fitted in the first place to give a radius of 2 ft. 9 in. to this joint, corresponding to a circumference of 17·27 ft., but these dimensions of course diminish as the wood blocks wear down.

The wood block beneath the joint G is increased in length beyond the other blocks, partly to increase the bearing surface on the pulley there, and also to make the halves of the strap, with its blocks &c., as divided by a vertical centre line, equal in weight. Then the effective load upon the brake is the load suspended by the rod at H, namely the weight of rod and washer-plates as measured with the bottom disc in water, together with the weights carried by the rod.

The ft.-lbs. of work per revolution then equals the effective weight W, multiplied by the circumference of the circle whose radius is C G, Fig. 16.

Putting W = total effective weight in lbs.

c = circumference in ft. of circle of radius C G.

n = number of revolutions in any time.

t = time in minutes.

then total ft.-lbs. of work done $= W \times c \times n$, and the mean actual brake H. P. $= \frac{W \times c \times n}{33000 \times t}$.

It is usual in trials of portable and other engines to let each exhibitor determine the mean speed in rev. per min. and the H. P. at which he wishes his engine to be tried. Let r be the rev. per min., and P be the power which he elects for; then the gross weight on the brake, must be

$$W = \frac{33000 \times P}{c \times r}$$

and from this must be subtracted the weight of the rod &c., to determine the apparent weights which must be applied.

The Rotary Hand Dynamometer illustrated in Figs. 29 and 30, Plate 38, was made in 1849, for testing small hand-worked machines, and has been in frequent use ever since for that purpose. Considering that very little information on the subject of rotary dynamometers was in existence at that date, it may be looked upon as a very ingenious design. It consists of a bed-plate and two **A** frames, carrying two parallel shafts A B and C D, connected by a pair of toothed wheels U and V, each 14 in. diam. and $1\frac{3}{4}$ in. wide. The first of these shafts A B is supported in parallel bearings in the usual way, and carries at one end a flywheel E, 3 ft. 10 in. diam., with a handle at 16 in. radius, for working it by manual power. The second shaft has a bearing of rounded internal section D at one end, to permit the shaft to incline slightly upwards at the other end. When the instrument is not in use this shaft rests in the bottom of a slot C in the **A** frame, arranged to permit it to rise and circle round the centre of the shaft A B. At its end D this shaft carries a belt pulley M, 2 ft. 7 in. diam. and 4 in. wide, from which any

machine to be tested is driven. A long lever F L encircles the two main shafts at C and A, and is prolonged to a heavy counterweight L at one end, and at the other suspends a Salter's spring balance F, attached to a cantilever projecting from the bed-plate. An oil cylinder G below the lever reduces any vibration which may arise in the apparatus. The lever is accurately bushed at A, so that the shaft A B can revolve within it, without allowing any transverse unsteadiness of the lever. The bush at C encircling the other shaft is rounded or knife-edged in the middle, to permit the shaft to rise in the slot as above described.

To the face of the weight L a counter N is attached. This is hinged at one end, with a spring behind it at the other, so as to press a small integrating disc contained in it against the face of a driving disc O, which is driven by a train of wheelwork P from the shaft A B. This wheelwork can be disconnected at pleasure by the clutch and handle Q; and it also drives a counter R, for registering the number of revolutions in a given time. The counterweight L, on the lever F L, must be adjusted lengthways, so as just to balance the lever and everything upon it about its bearing on the shaft A B. This includes such proportion of the weight of the shaft C D, and the toothed wheel V upon it, as would naturally be supported at C. To be accurate, half of the weight of the driving belt should at the same time be suspended from the driving pulley M, as that also must be balanced.

The counter N is then shifted longitudinally on the face of the weight, till the integrating disc N is exactly opposite the centre of the disc O, when the lever is at the right height. The screw above the spring balance F must then be adjusted, till the integrating disc N is exactly at the right height. The spring balance should now stand at zero on its scale, otherwise the balance of the lever must be further corrected with small weights suspended in suitable positions; the instrument is then in correct adjustment. Any machine to be tested is brought up, and a belt applied to the pulley M, so that the two sides of it will leave it in an average horizontal direction. If materially inclined, the true balance is disturbed by the vertical component of the pull of the belt.

The instrument is usually worked by two men, at nearly uniform speeds, regulated by the vibration of an adjustable pendulum S suspended to the frame. The instrument being in true adjustment, the ft.-lbs. of work done in any revolution is manifestly equal to the pull in lbs. upon the spring balance F, multiplied by the circumference in ft. of the circle whose radius is A F. This can be equated to the index recorded by the integrating counter N, multiplied by a constant C, which can be determined inversely by pressing the lever upwards till the Salter's spring balance records a certain strain, and then noting the integration recorded by the counter N in a given number of revolutions, as per the revolution counter R.

Then if W = strain on spring balance in lbs.

c = circumference in ft. of circle of radius A F.

n = revolutions of integrating counter.

N = revolutions of handwheel as per revolution counter.

The ft.-lbs. of work done, $N \times c \times W = C \times n$. Therefore $C = \frac{N \times c \times W}{n}$.

If the instrument is not in perfect adjustment when tested, and successive readings with different loads on the spring are not exactly proportional to those loads, in consequence of there having been some initial strain or slackness at F when the integrating disc was at zero on the driving disc, it will generally be found that the readings can be made proportional to one another, by adding to or subtracting from each reading the product of a constant K into the revolutions N. The way of dealing with this sort of correction was fully treated of in the previous description of the plough dynamometer. The result is that in all subsequent calculations $(n \pm KN)$ must be substituted for n.

Then the ft.-lbs. of work done $= C\,(n \pm KN)$

and $C = \frac{N \times c \times W}{n \pm KN}$

The actual instrument under review was proportioned to give as nearly as possible the actual ft.-lbs. of work done in the figures on the integrating counter, so as to avoid all subsequent calculations, as C then becomes $= 1$. The last time it was tested with three successive loads it gave $C = 1$, $K = +17$; so that in the subsequent trials the ft.-lbs. of work done was determined to be $= n + 17\,N$. A little more care in previous adjustment might have reduced

K to 0; then the ft.-lbs. of work would have equalled n. The principle of this instrument is believed to have been original, and some points in the arrangement are well worthy of consideration in designing rotary dynamometers of larger power. In the details however there is room for improvement, the greatest difficulty in the use of it being the accurate balancing of the lever, and the adjustment of the integrating disc. It should further be remarked that the integrating disc does not move exactly radially across the face of the driving disc O, but in an arc of a circle having its centre at A. The slightest transverse twisting of the lever and counterweight L, or slackness of the counter in its hinges, is liable to move the integrating disc N on the face of the driving disc O, thus falsifying all tests and subsequent trials. It should further be remarked also that the range of travel of the integrating disc on the driving disc with average loads is very small. The instrument was made in the first place without an integrating arrangement, which was added a few years subsequently.

Large Rotary Dynamometers.—The Society possesses two of these machines. The smaller only is described in this paper, and is proportioned for working to a maximum of 20 H. P. at 120 rev. per min., for testing threshing and other machines worked by ordinary portable engines. The second instrument is similar in principle but larger, being capable of working up to 50 H. P.; it was made specially for testing roundabout ploughing tackle in 1864. Successive editions of the 20 H. P. dynamometer appear to have been made in 1850, 1854, and 1860, for testing threshing machines, each being an improvement on the preceding instrument. The first named was indeed rather smaller in size, and was made for testing threshing machines driven by horses, and it was not furnished with integrating apparatus. The last named is the only one now existing.

The 20 H. P. Rotary Dynamometer is shown in Figs. 26 to 28, Plate 37, and consists primarily of a pair of well-balanced fast and loose pulleys A and B, on a shaft C D which is carried in bearings on two A frames, supported on a timber carriage. The pulley A is

keyed tight on the shaft, and the power of the engine or other prime mover is conveyed to the dynamometer either by a belt on this pulley, or by a universal coupling shaft E on one end of the machine. The machine under trial is driven by a belt from the pulley B, which though loose upon the shaft is connected with the pulley A by a series of springs, which permit it to lag behind the pulley A, the angles of twist being proportional to the effective strain transmitted by B.

The springs are arranged in the following manner. The boss of the pulley B projects 2 inches beyond the edge of its rim, which nearly touches the edge of the rim of A; while from the inside of the rim of A two flat plates F F at opposite sides project into the pulley B, Figs. 26 and 28. To the boss of B and its elongation, four curved springs, shaped like short watch-springs, and each 2 in. wide by $\frac{5}{16}$ in. thick, are attached as shown. Two of these G G, near the centre arms of B, wind outwards in one direction, and are attached to the pulley A at its rim by means of the arms F F above referred to. The other two springs H H, on the prolongation of the boss of B, wind outwards in the opposite direction, and are attached direct to the rim of A. The object of arranging the springs in opposite directions is to neutralise the effects of centrifugal force upon them, the earlier instruments with springs in only one direction having given much trouble from that cause; it also has the effect probably of making the angles of twist between the pulleys vary more exactly with the moment of the twisting couple between them.

The pulley B is retained accurately in one position endways on the shaft by a collar on one side, and the boss of A on the other. On the boss of B, facing the bearing C, a very short piece of a coarse-pitched double-threaded brass screw K is pinned, and these threads bear against a small crosshead L, which is passed through a slot in the shaft, and has its ends bevilled off to partial screw threads, so as to fit on the screw K, as shown to a larger scale in Figs. 23 to 25, Plate 36. The slot through the shaft extends nearly to the bearing C, thus giving the crosshead L freedom to slide along it in the direction of the bearing. From its extremity at M to the slot the shaft is bored out, and a small rod N passes

up this bore, and is screwed to the crosshead L. A light spiral spring encircles this rod in the bore, and presses the crosshead L lightly against the screw K, the resistance at its other end being produced by the screwed bush at M.

The rod N is prolonged beyond the end of the main shaft, to work the slide O of a counter and disc integrating apparatus, Figs. 22 and 23. The slide works in V grooves, and contains in itself an integrating disc P, supported on brackets projecting from the side, with its integrating counter Q, and a pencil for recording diagrams on a paper cylinder R. The driving disc S, the revolution counter T, and the paper cylinder turning gear are driven by means of a small spur pinion contained on the nut which is screwed into the main shaft at M. This pinion gears into a wheel on the counter apparatus, and thence the various motions are conveyed by bevil and other wheels, with a disconnecting clutch at V for stopping and starting the recording apparatus at pleasure.

Inasmuch as the angle moved through by the loose pulley B, relatively to the fast one A, varies nearly as the load on the springs, the travel of the crosshead L and slide Q, being worked longitudinally by uniform screw-threads, must vary in the same ratio. It follows from this that the motion of the pencil on the paper cylinder, and the radius of contact of the integrating disc P on the driving disc S, will also vary uniformly with the twisting moment, if they are adjusted to their respective zeros when the springs are unloaded and free in both directions.

The work done in ft.-lbs. can consequently be represented as the product of a constant C into the revolutions recorded by the integrating counter, in the same way as in the plough and hand rotary dynamometers described above, the integrating apparatus now under review being on exactly the same principle as theirs.

Let n = revolutions of integrating disc as recorded by its counter.

Then the ft.-lbs. of work done in any experiment $= C \times n$.

The constant C is usually determined by securing the shaft and fast pulley A, and loading the loose pulley B with a known weight W, suspended on one side by a small cord wound round its rim and attached elsewhere, the discs and other parts having

been previously adjusted accurately. Then the clutch at V being disconnected, the registering apparatus is turned round by hand till any number of revolutions of the dynamometer is recorded by the counter T.

Let N = such revolutions of dynamometer.
c = circumference of pulley in ft.
W = weight in lbs. applied to its circumference.
n = revolutions recorded by integrating counter when N is taken.

Then the ft.-lbs. of work may be represented by either of the expressions, $N \times c \times W$, or $C \times n$.

Therefore $N \times c \times W = C \times n$

and $C = \frac{N \times c \times W}{n}$.

The test should be repeated with increased loads, and should be applied at different parts of the circumference of B, to eliminate errors arising from lack of balance of the pulley B, and to determine whether any material correction K, as in the plough dynamometer, must be taken into account, in consequence of imperfect adjustment at starting. The constant C of these springs now in use, when last determined, was almost exactly 50,000, and no correction K was necessary. For the maximum twisting moments which this dynamometer is capable of transmitting, annular rings are put on to the pulleys A and B, to increase their diameters to 4 ft. 6 in.

In the 50 H. P. Rotary Dynamometer the chief difference from the 20 H. P. dynamometer described above is that it is provided with six straight radial springs attached to the projecting boss of the loose pulley B, and bearing against rollers projecting from the arms of the fast pulley A just within its rim. The springs are thin flat tapered plates, proportioned to act as cantilevers supported at the centre boss and loaded at the bearing rollers at their outer ends. The writer prefers this arrangement to that of the curved springs in the smaller instrument, believing that the angles moved through by the straight springs must vary more uniformly with the twisting moments than in the curved springs previously described; but unfortunately he has had no personal experience in using this

dynamometer. In a recent duplicate of the 20 H.P. dynamometer made for the Chilian Exhibition Commissioners, the screw K and crosshead L that communicate the deflection of the springs to the integrating wheel have been replaced by a pair of bevil wheels at the boss of the loose pulley, and a pinion and rack inside a slot in the shaft, the rod of the integrating apparatus being attached to this rack.

The writer regrets that he is but imperfectly acquainted with the history of dynamometer designs. Spring links for testing draughts of vehicles are undoubtedly very old, and he has found records of a well-designed instrument of this kind used by M. Prony at the Ecole Polytechnique in Paris at the end of the last century. At the present time Messrs. Salter of Westbromwich make several varieties of this simple instrument. The friction brake in its original shape is attributed to M. Prony, but it was very much improved by the late Mr. Appold, by the introduction of a differential adjustment very similar to that now in use as described above, his first application of this addition being to some crank brakes for prison labour at Bridewell some years before the Royal Agricultural Society began to test steam engines. This brake was also applied with great success to telegraph-cable laying machinery. General Morin is the highest authority who has written on the subject of integrating traction and rotary dynamometers. In a paper dated 1841, "Sur divers Appareils dynamométriques," he describes several dynamometers with the integrating disc arrangement adopted in later years in the Society's instruments above described, and also Ernst's planimeter, an arrangement of a disc running on a cone, for effecting a similar object. At the end of his paper he attributes most of the designs described by him to his friend and instructor Ponceclet. Mr. Froude has enriched the proceedings of this Institution with his original paper on dynamometers in 1858.

All the Society's instruments excepting the spring links have been made by the late firm of Easton and Amos, now Eastons and Anderson, who since the year 1848 have been consulting engineers to the Royal Agricultural Society, and custodians of its apparatus.

The arrangement of all the older instruments was the work of Mr. C. E. Amos, while the merit of some of the most ingenious contrivances must be shared between him and the late Mr. Appold, whose rare inventive genius left its mark on everything he touched. The writer's experience in the use and testing of them has been gained at the last six annual implement trial meetings of the Society, at which they have been the means of affording some very valuable statistics. A very powerful traction dynamometer with ten pairs of springs was made recently by the Society's engineers for the Indian State Railways.

Mr. RICH exhibited the spring links or dial balances belonging to the Royal Agricultural Society, the plough dynamometer, the long flat spring of the horse dynamometer, and the counter and disc integrating apparatus of the 20 H. P. large rotary dynamometer described in the paper.

Mr. F. J. BRAMWELL said he did not propose to discuss the subject of the paper, because that paper dealt with it in so complete a manner that he had nothing to add to it. It had been his lot to work with these instruments very often, at the Royal Agricultural Society's trials, and therefore he knew their merits in practice. He wished however to be allowed to lay before the meeting two matters in connection with the subject of dynamometers. One was a very simple mode of making rapidly a dynamometer, which, although not by any means so accurate as the instruments which had been described in the paper, was sufficient for the purpose of giving a rough estimate of the power exerted by a portable engine in doing any particular work; the plan was the invention he believed of one of Messrs. Ransomes Sims and Head's managers. Over the driving pulley of the engine to be tried was laid a leather friction strap, to one end of which was attached the weight to be lifted, while the other end was fixed to an ordinary spring-balance.

The engine was then set to work to lift the weight, and supposing the gross weight suspended from the strap was 100 lb., and that when it was held up from the ground by the engine the spring-balance indicated 20 lb., then the effective weight lifted by the engine would be 80 lb. Suppose the friction increased and the band began to wind the weight up, so that the tension upon the spring was reduced to say 18 lb.; then the effective weight would be 82 lb., and that would restore the balance of work. If on the other hand there was not friction enough, and the weight began to fall, the spiral spring would be extended and the effective weight would be lightened, because the spiral spring by its range of motion would take an increased portion of the strain and thus cause a deduction from the weight at the other end of the strap. This contrivance was knocked up in two or three hours on one occasion alongside the Nile at Cairo, when he was trying one of Messrs. Ransomes' engines for burning cotton stalks and straw, and it worked in an extremely efficient manner, with little variation. He mentioned it as a mode by which any one who had to make a trial of a portable engine, and had not a dynamometer at hand such as that described in the paper, could do it for himself with a common strap, weight, and spring-balance which he might take off the safety-valve of an engine.

The next thing to which he wished to call attention was an improvement that had been made by Mr. James Thomson of Glasgow in the integrating apparatus described in the paper, which improvement had been exhibited at a meeting of the Royal Society this spring. The small integrating wheel shown in the drawing, as it traversed radially across the face of the large disc, did so by a rubbing motion, and the wheel therefore suffered to a certain extent. Mr. Thomson's invention was to change that rubbing motion to a rolling motion by the employment of a sphere, the only rubbing motion remaining being that which was due to the light contact of the sphere with a fork or pair of prongs which caused its lateral movement. The large disc was laid with its face inclined, instead of vertically; and across the lower half of its face, but not touching it, was carried a horizontal roller; then, lying supported by the disc and by the roller, there was a sphere, which was opposite the centre of the

disc when the instrument was at rest; the sphere was held in the fork, by which it was moved across the face of the disc in accordance with the particular strain upon the instrument at any time in working, the movement being thus done by a rolling motion. The large disc communicated its motion to the sphere, and the sphere communicated its motion to the cylinder, and the cylinder worked the registering apparatus. By that contrivance every rubbing motion was got rid of, except the mere light contact of the fork which embraced the ball.

Mr. E. A. COWPER did not think that by the employment of a sphere in the manner just described an absolute rolling motion was obtained, and that it was mathematically correct. He had seen Mr. Thomson's instrument in the South Kensington Exhibition, and it was a very nice apparatus, and the motion was a very good one; but it was not quite perfect. The surface of the cylinder moved of course with a truly circular motion round its axis, without any twisting; but the disc was moving round an axis at right angles to that of the cylinder, so that if the ball rolled fairly against the cylinder it did not roll fairly against the disc. The ball rolled very well, but it could not roll quite truly; and of course there was the little friction of the two prongs of the fork holding the ball. The whole power communicated from the disc to the cylinder or from the cylinder to the disc was by means of the weight of the heavy brass ball lying between the two. He certainly preferred the arrangement shown in the drawings and described in the paper, having the small integrating wheel in contact with the face of the large disc. In that case the edge of the small wheel was rounded, and might be imagined to form a portion of a ball that was rolling in contact with the disc, in as perfect a manner as the ball in the former case.

But there was another mode of taking up the motion, which he thought was better, namely the conical one alluded to in the paper as Ernst's planimeter. It was invented by Mr. Henry Chapman, and used by him in 1840; but he thought it had been previously invented by M. Ernst. The small integrating wheel by which the

motion was taken up ran in contact with the surface of a cone, the axis of which was in the same plane with that of the wheel, but inclined to it at half the angle of the cone, so that the side of the cone on which the integrating wheel ran was parallel to the axis of the wheel. When the wheel was running in its middle position—namely where the diameter of the cone at the point of contact was proportioned to the wheel as the speeds—there was no relative motion, and this was therefore the zero line upon the paper recording-cylinder. If the wheel were moved further away from the apex of the cone, it ran upon a larger diameter; and if nearer to the apex, upon a smaller diameter; in either case giving a difference in the motion. Now the edge of that little integrating wheel was more nearly conforming to the surface of the cone; therefore the surface at the edge might even be made a very flat curve, so as to have a good bite on the cone, in consequence of being able to bear a good pressure without bruising the metal; and it did not twist so much as a wheel running upon the face of a flat disc in the arrangement described in the paper. The instrument was invented for taking the profile of roads in levelling; it was placed on a four-wheel carriage, and a very heavy pendulum was connected to it, so that as the machine went up or down hill the pendulum hung vertically, and drew a complete profile of the road upon a paper cylinder.

Mr. A. PAGET thought one great advantage of the ball apparatus described by Mr. Bramwell would be that it obviated the loss of the true proportion in the movements by the wearing of the circumference of the small integrating wheel in the arrangement described in the paper. The wearing of the cylinder actuated by the ball would be infinitesimally small, whereas the wear on the edge of the small wheel must be considerable. In the ball apparatus the larger part of the wear would take place on the ball itself, and therefore the proportion of the motions would be kept true. That would he thought be a great advantage connected with the ball arrangement, which would not attend the conical plan just described.

Mr. H. DARWIN described a proposed dead-weight rotary dynamometer, designed by himself at Messrs. Eastons and Anderson's works, for obviating the use of a spring, by employing a system of rods and a weight, whereby the distance of the integrating wheel from the centre of the large disc was always proportional to the moment of the force turning the dynamometer. The principle of the arrangement is illustrated in the diagram, Fig. 34, Plate 39, in which the line O G represents a rod capable of turning freely in the plane of the paper about the fixed point O; at G it is pivoted to the centre of a rod A G B, which is twice the length of O G. Then the point B being guided to move in the vertical line O B, the other end A of the rod will necessarily move in the horizontal line O A, in consequence of the property that the angle contained in a semicircle is a right angle; this is in fact the principle of the ordinary grasshopper parallel motion. At B a weight W is suspended, and at A a horizontal force P acts which is proportional to the moment turning the dynamometer. As the rod O G can turn freely at O, the reaction at G must be in the direction G O, when there is equilibrium; and as there are three forces acting on the rod A G B, two of which—namely the horizontal force P and the reaction at G—have their directions meeting at the point O, the direction of the third force must also pass through the same point O; that is to say, neglecting the weight of the rods, there will be no reaction between the end B and its guides. The directions of these three forces being parallel to the sides of the triangle O H G, their magnitudes are proportional to the length of its sides, and therefore the force P varies as the tangent of the angle which the rod O G makes with the vertical, as W is a constant. Consequently the further the point A moves from O, the greater P becomes; and when the rods O G and A B are vertical, P is nothing. If the rod G O be prolonged in a straight line beyond the fixed centre O, and F be its intersection with a horizontal line drawn through any point E in the vertical line E O B, the distance of F from E will evidently vary as the tangent of the angle which O G makes with the vertical, and therefore as the force P. This force being proportional to the moment turning the dynamometer, it follows that if

the small integrating wheel be made to move towards or from the centre of the disc as the point F moves towards or from E, the counter attached to the integrating wheel will register a number proportional to the work passing through the machine. The weights of the rods O G and A B, which have here been neglected, will only have the effect of causing a slight reaction between the end B and its guides, and of adding a small amount to the weight W; and this will cause no error in the action of the machine constructed upon this principle.

In Figs. 31 to 33, Plate 39, are shown an elevation and plan of the rotary dynamometer designed on this principle; the only difference being that the point B from which the weight is suspended is guided in an arc of a circle by means of a radius rod of suitable length, as this will cause less friction than a block sliding between guides, and will produce no sensible error. If requisite a dash-pot could be attached below the weight; but as the inertia of the weight will tend to reduce oscillations, this may not be necessary. The counter C and integrating wheel I form a small carriage, the weight of which is supported at one end by the integrating wheel itself resting on the face of the large horizontal disc D, and thus causing sufficient pressure to produce rotation of the wheel when the disc rotates; and the other end of the carriage is supported by a pair of wheels running on horizontal rails. On the axle of these carrying wheels are two loose rollers, against each of which presses one arm of the fork F on the end of the rod O G, and thus the carriage and integrating wheel are moved backwards and forwards as the fork moves; the arms of the fork are held together by a spring, so that no backlash can take place. The integrating wheel I is adjusted so as to be at the centre of the disc D when the fork F and rod O G are vertical; hence its distance from the centre of the disc at any time is proportional to the force P.

The pulley N, driven by a belt from the engine, is keyed upon the main shaft S, on which is also carried a loose pulley R of the same diameter, for driving the machine to be tested. The shaft S is made hollow, and inside it slides a flat iron bar, the outer end of which is connected to the end A of the rod A B by a swivel joint,

allowing the bar to rotate with the shaft; the inner end of the bar is attached to a short chain, which is fastened to the circumference of the small wheel J, a slot being cut in the shaft S to admit the rim of the wheel for this purpose. The spindle L of the wheel J is supported by brackets bolted to the side of the fast pulley N; and on one end of the spindle is keyed another small wheel K, with a short chain fastened to its circumference, the other end of the chain being attached to a sector of a circle M cast on the side of the loose pulley R. The whole force that drives the loose pulley is thus transmitted through this chain, the tension of which is therefore proportional to the driving force; and this tension being communicated directly through the wheel J and the sliding bar to the point A, the distance of the integrating wheel from the centre of the disc D is proportional to the power driving the machine that is being tested.

The constant for this dynamometer will not have to be determined every time the instrument is used; when once known it will not alter with use. It may be determined in the ordinary way by hanging known weights to the circumference of the loose pulley, and turning the disc D a known number of times, and then reading the counter; but it could probably be ascertained with greater accuracy by calculation, and it could be made equal to any convenient number by constructing the parts with proper dimensions. For the particular case of the instrument shown in the drawings the constant would be 1·557; and the ft.-lbs. of work transmitted through the dynamometer would consequently be the product of the weight W in lbs., multiplied by the reading of the counter and by 1·557. The integrating wheel I can be adjusted to its proper position with great accuracy, by placing the rod A B vertical with a plumb-bob, and then placing the wheel exactly at the centre of the disc D by means of an adjusting screw; this would be a permanent adjustment. For any case where great accuracy was required, a greater travel could be given to the integrating wheel by lengthening the fork F, at the same time making the disc D of larger diameter and placing it at a greater height above the point O. Centrifugal force will not affect the

action of this instrument; but in dynamometers in which the springs rotate it is impossible to be sure that an error is not introduced from this cause. A slightly modified form of this dynamometer might with advantage be permanently applied to shop or factory shafting, whereby the relative economic values of different coals might be tested with great ease and accuracy, and also the relative values of different oils could be ascertained, both of which would tend to economise coal to a great extent; the spring dynamometer could not well be applied for this purpose, as the coefficient of the spring would vary too much under such a constant strain. The friction of the joints in the linkwork of this dead-weight dynamometer is no doubt a fault, as it is important that the relative motion of the engine pulley N and the machine pulley R should take place with as little friction as possible. The friction of the linkwork however must be of small importance compared with that of the loose pulley R upon the shaft, as the shaft is of large diameter and the pressure of the pulley-boss against it is great, owing to the tension of the belt. This friction might be lessened by using some sort of friction rollers; in which case the relative motion of the two pulleys would take place with very little friction.

Mr. E. H. CARBUTT observed it was mentioned in the paper that a powerful traction dynamometer had been made for the Indian State Railways, and he should be glad to know whether it had answered there. It was a thing that most railway companies in this country would be glad to get; they were now having the battle of the carriages, long and short carriages, Pullman cars and others, and he was sure it would facilitate many of the experiments if they had a good dynamometer. He should be glad to know what report had been received from India on this subject. A similar machine exhibited at the Vienna Exhibition in 1873 was said to work well, but no definite information could be obtained of its working.

Mr. RICH said he had not heard anything of the working of the traction dynamometer sent out to the Indian State Railways since

its arrival in India; but he saw no reason why it should not be as good and accurate an instrument as the horse dynamometer, which was very similar in principle. It was fixed in a light covered wagon, with wrought-iron frames and central buffer and drawbar, which was available for other purposes when the dynamometer was removed. In the centre of the carriage framing a space was kept clear for the reception of 20 flat springs, laid transversely, each 4 ft. long and fitted with three pin joints, being almost identical with the spring plates in the horse dynamometer. The springs were all connected and kept at uniform distances apart by longitudinal links pinned to their outer ends. The leading draught-bar, to which the engine was coupled, was attached to the carriage in the usual way. The ten front springs were attached at their centres rigidly to the carriage frame. The trailing drawbar was prolonged to embrace the ten back springs at their middle pins, and to it was connected a lever which went up to an integrating apparatus in the carriage body, having also a continuous paper roll on which variations of draught were marked by a pencil. With all the springs in use the instrument was suited for maximum draughts of 15,000 lbs., but any number of pairs of springs could be easily removed for testing smaller draughts.

Mr. T. AVELING said he had had a considerable amount of experience in the use of the friction brake dynamometer, in common with the numerous engineers engaged in the manufacture of agricultural engines; and he had sometimes looked at that machine as a sort of instrument of torture, because when the engines went upon the brake there was no mistake about it, the actual duty that the engine did was registered, and registered in a manner that was thoroughly satisfactory as to accuracy, and the engine makers knew that when a decision had been arrived at by the use of that machine it had been arrived at honestly. It had been used a good deal lately for some agricultural associations with which he was connected in the county of Kent. They had been giving up some of the old prizes formerly awarded to the agricultural labourers; and they thought it advisable to give prizes to the men working the agricultural engines,

so that their efficiency might be tested. He had lately superintended the trials of upwards of forty men with one of the friction brake dynamometers, and the necessity for such trials had been very plainly shown; for in some cases with a consumption of 220 lb. of coal a man had produced only 7,500 revolutions of the brake wheel, while others had produced 17,000 revolutions with the same engine. That the instrument was an extremely valuable one he was certain; the present state of the efficiency of agricultural engines was dependent entirely upon the use of it. He thought that not only the agricultural interest generally, but the Royal Agricultural Society also, were very much indebted to those who had originally brought out that dynamometer.

Mr. W. H. MAW remarked upon the coupling of the two ends of the brake strap to the pendulum lever in the friction brake dynamometer, that he thought upon the way in which the ends were coupled depended to a certain extent the correct action of the instrument. Supposing for instance that the weight hanging on the brake required a tension of 100 lbs. on the brake strap, and that the lengths of the two arms AC and AB of the pendulum lever (Fig. 21, Plate 36) were as 10 to 9, then if the two ends of the strap were led off from the pendulum lever at the same angle it was evident that the tension on the end which was attached to the outer end C of the lever would be only nine tenths of that on the other end attached to the intermediate point B of the lever, and thus there would be a difference of 10 lbs. acting in favour of the load on the brake. The way in which that could be got over was by causing the two ends of the brake strap BD and CE to leave the pendulum lever at different angles; so that with an equal tensile strain upon the two ends of the strap, the equivalent strains acting along BD and CF at right angles to the lever at the two points of attachment of the strap to the latter should nevertheless be inversely proportional to the lengths of the arms. In the large brake described in the paper, which was now at the South Kensington Exhibition of scientific apparatus, the end of the pendulum lever

was bent out of the straight line, and from a rough measurement of the angle he found it was so adjusted that the tangential strains at the ends of the two arms were about in the required proportion to produce an equal tensile strain upon each half of the brake strap. He should be glad to know whether that was done intentionally, and whether an adjustment of that kind had been found necessary from the results of working. In all the older brakes he thought the pendulum levers were straight, and there was no attempt at any adjustment of that kind.

There was another point that he noticed in the drawing shown of the friction brake dynamometer; the rims of the brake wheels were made convex transversely like an ordinary belt pulley. He had found in running some brakes under various circumstances that they acted better if the rims were flat; the lubrication was then more equal over the whole surface. If the brakes ran very fast with a slightly convex rim, the oil was apt to get more in the centre of the rim, leaving the edges imperfectly lubricated; he had had difficulties with very wide brakes from that cause.

He should be glad to know also what was the maximum power that had ever been absorbed by the brake shown in Fig. 17, which was stated to have been proportioned for 100 H. P. at 100 rev. per min. The three brake wheels being each 5 ft. diameter and 7 in. wide, he found that the number of inches in their aggregate width (21 in.), multiplied by the velocity of the rim in ft. per min., and divided by the 100 H. P. to be taken off, gave as a result the constant number 330 per H.P.; but in a number of experiments which he had once tried with a brake of a rather smaller diameter than that, he had found that there was a great difficulty in keeping the rim cool if the constant number obtained in that way came lower than 700 per H. P. taken off; which was about double the number obtained with the brake described in the paper. In other words, he should expect this brake to absorb only about 16 H. P. for each of its three wheels at the speed stated. Of course by a very careful lubrication the brake could be kept cool with the very low constant of 330 pertaining to the proportions given in the paper; but in running for a long time it was necessary to have a higher constant.

He thought the principal reason why it was necessary to attend to this point was that the tension of the strap varied with each kind of lubrication. For instance, if the lubrication were so perfect that the tension on the brake strap necessary to sustain a given load became trebled, then the effect of the inequality in the tangential strains at the two ends of the strap became trebled also. The result was therefore different, according as the brake was lubricated badly or well; the difference he believed was generally found from experience to be very slight between good and bad lubrication. amounting he thought to only about 3 per cent. less resistance opposed by a brake when well than when indifferently lubricated, the actual load hanging on the brake being the same in both cases; but he thought the difference might rise to as much as about 8 per cent. between very good and very bad lubrication.

Mr. E. A. COWPER observed there was truth in the observations just made about the loss of power or gain of power by the fixed point against which the lever of the brake acted in the dynamometer. He remembered pointing it out at the Oxford meeting of the Royal Agricultural Society in 1870, and the conclusion then arrived at was that there was a certain very small amount of error from that cause, but that it was equal and uniform throughout all the experiments. The fixed point must be placed to slack the brake, therefore it helped the weight up, and there was so much less real weight upon the brake than was apparent; it thus made a slight error in the total amount of power in favour of the coal. The extent of this error was extremely small, when it was considered that the light pressure of the tail end of the lever was only acting against the fixed point at a very small radius, as it was placed near the shaft.

Mr. T. ADAMS observed that three kinds of springs had been illustrated in the dynamometers described in the paper: there was the spiral spring made of a uniformly parallel coiled bar; there was the spring link with curved sides, subjected to a longitudinal pull; and there was the flat plate spring made up of two parallel

straight bars tapering in thickness and subjected to a transverse pull. He should be glad to know what was the behaviour of each of these springs under successive increments and decrements of load, in relation to the space passed through by any fixed point in each of the springs.

Mr. RICH said that the simple mode of constructing a friction brake, which had been described by Mr. Bramwell, was new to him; he had known several instances in his experience in which he could have applied such an arrangement with advantage in the absence of a regular friction brake for testing turbines and other prime movers.

With regard to the integrating cone described by Mr. Cowper, Gen. Morin mentioned it as applied to dynamometers as though it was not a very new thing in 1841, and he spoke of it as Ernst's.

With regard to the question whether the old friction brakes had the peculiar angle at the bottom of the pendulum levers, which Mr. Maw had shown was desirable there, it was a fact that the 100 H. P. friction brake described in the paper had that angle, and the differential levers in the older 20 H. P. brakes which had been made from 1848 under Mr. Appold's care were exactly similar. It might have been accidental that the angle had been preserved, but he had never noticed the point before; he thought it most likely that Mr. Appold had arrived at that particular angle for the pendulum levers.

As regarded the power which that brake was capable of absorbing in friction without heating the pulleys to an undue extent, it was intended for a maximum of 100 H. P., but he should put the speed for that power at 150 instead of 100 revolutions per min. It had never been necessary as yet to work it at more than 40 H. P. at 150 revolutions with straps on two pulleys; the smaller brakes with only one pulley had been run up occasionally to 20 or 25 H. P. at 120 revolutions without any great difficulty.

With reference to the question as to the shape of the springs, and the relative advantages of using the different kinds, he supposed the highest authority on the subject of springs was Mr. Froude, by

whom the strength and range of a spring were referred altogether to the weight of metal and to its being properly applied. With all these dynamometers the great thing was to get plenty of range, and to get accuracy of movement in proportion to the load. The objection to the spiral spring used in the plough dynamometer was that it bore on the edge instead of bearing in the middle, and it was necessary to press upon it in order to hold it in its position; and another objection was that it gave frequently only a very small range. The advantage of the long flat spring used in the horse dynamometer was that if greater range were wanted it was only necessary to lengthen the spring, and to increase its width and thickness proportionally. It would not do to have ordinary flat plate springs, composed of three or four plates one behind the other as in carriage springs, because there would be a certain amount of friction between the plates which would injure the true relation of the pull and the range of spring; so that it was necessary to have only two plates in the spring, and to have them accurately connected at the ends in the manner shown, so as to move freely. He believed this was about the best construction of spring used for the purpose of dynamometers; it was very similar to what had been used by Morin in 1840. With regard to the curved springs in the 20 H. P. rotary dynamometer, he could not say that he had tested them with extreme accuracy; but he thought it scarcely likely that they would give angular deflections varying exactly uniformly with the loads transmitted to any great range. Considering their shape it would seem almost unnatural that they should do so; but in actual tests of the instrument with varying loads up to the maximum working limits the determinations of the co-efficient from the several results generally agreed fairly with one another. He must own he preferred the straight radial springs in the 50 H. P. dynamometer named in the paper. It was worthy of remark that, to get plenty of range with dynamometer springs, they should be of uniform strength everywhere and not too strong. If stops were provided to limit their deflections, the corresponding maximum working loads might be as much as 50 to 75 per cent. of the loads which would produce permanent set.

The PRESIDENT said that in his own personal experience he had had great reason to doubt the accuracy of the present theory with respect to friction brakes. He had noticed that friction brakes always gave a result in favour of the machine, very much higher than any other description of brake. Now he thought there was no warrant for assuming that all other sorts of brake were inferior to the friction brake; and therefore it might be suspected that the friction brake admitted some particular form of error, the nature of which had not perhaps been sufficiently discussed, or the amount of which at all events had not been recognised. He would illustrate his meaning by supposing that a sliding body on the table had a horizontal cord attached to it, passing over a pulley at the end of the table, with a weight suspended at the end of the cord; and let the sliding body be set in uniform motion by means of that weight. Now if he just tapped the underside of the table with a quick succession of raps, the sliding body would travel much faster, and the weight at the end of the cord would descend much faster, though all other things were the same in the one case as in the other. But this was exactly what occurred in the case of the agricultural engines which returned such a high amount of duty; the brake wheel from which the friction was ascertained was always in a dithering state, a vibration being set up in working exactly like that which he had produced by tapping the underside of the table. Hence it was that a result was obtained from the brake, whatever might be the cause of it, which wanted reducing—and he thought it could be reduced—to scientific expression. Results were got from the friction brake, however applied and to whatever it might be applied, of a much higher kind than were got from any other description of brake whatever. He thought the only way of putting it to the test would be by taking a deep coal pit, such as the Monkwearmouth coal pit, and setting a friction brake at work over it with a descending weight; it would be known how far the weight had descended and in what time, and from that the exact horse power exerted could be ascertained. It would then be seen what result was obtained by admeasurement from the brake itself; and he ventured to say a much higher power would be

returned by the brake than was actually exerted by the descending weight. That was his own experience, and perhaps some of the members might have an opportunity for trying experiments of that kind, and this would be well worth doing.

Mr. F. J. BRAMWELL said that since his attention had been called to this matter by the President some years ago, his confidence in the absolute certainty of these friction brakes had been very much shaken. The Royal Agricultural Society, under the advice of their engineers and judges, had endeavoured of late years to see whether these brakes were to be relied upon; and they had endeavoured to do so by taking the indicator diagrams from the engines and carefully comparing them with the brake results. Now there was no doubt that generally speaking the difference between the brake horse power and the indicated horse power had been found to be no greater than might have been expected from the friction of the engine itself. The average result arrived at, as far as he remembered, was that the difference between the gross indicated horse power and the brake horse power amounted to between 16 and 17 per cent.; but most certainly there were some cases where there were very anomalous results, some cases so anomalous that the judges did not know what to say about them or how to deal with them. He was inclined to think that the President's suspicions of the friction brake were well founded, and he thought that it would be most desirable that these experiments should be made, but he did not think that the error in practice was so great as the President believed it to be, because the indicator results of the engines justified in most cases the high results obtained by the brake.

Mr. E. A. COWPER remarked that, in the illustration suggested by the President, supposing that the sliding body on the table was standing still, and that the weight was added gradually at the end of the cord till the sliding body moved, then as soon as it moved it would proceed to run quicker; and then more load would have to be put on it to check the speed; and that was what was done with the friction brakes. It was not the stand-still friction, it was the

running friction which was in action in the working of the brakes. If one of those brakes were loaded to the extent of the stand-still friction, and the wheel were turned gently, it would lift up the weight; but when running it would not lift up so heavy a weight. The weight must be put on while the brake was running, and then it would be always held up; it was therefore not the power required to move the weight when standing still that was recorded by the brake, but the power required when it was moving.

The PRESIDENT said he had proposed, in the illustration he had offered, that the weight, the friction of which was to be tested, should have attained the state of uniform motion, before bringing into play the effect of vibration.

Mr. A. PAGET observed it had been suggested that it would be very desirable that some of the members as individuals should conduct experiments to settle this point about the friction brake, and it was very evident that all were agreed the point should be settled; but he thought that it ought not to be left to the chance of some mechanical engineers as individuals settling the point, but that the Institution of Mechanical Engineers as a body should undertake to settle the point as part of their work as an institution. He thought it was a disgrace to them that the Royal Agricultural Society had done so much in this matter, which was one of vital consequence to mechanical engineers, while the Institution of Mechanical Engineers had done so little.

The PRESIDENT moved a vote of thanks to Mr. Rich for his paper, which was passed.

The following paper was then read :—

ON MECHANICAL PUDDLING.

BY MR. T. RUSSELL CRAMPTON, OF LONDON.

In introducing this paper to the meeting, the author trusts his observations may lead to instructive discussion, both with regard to solving the problem of Mechanical Puddling, and to the effect which the substitution of machinery for hand labour may have on the future of the iron trade; and he feels that it is a subject eminently fitted for the consideration of the members of this Institution, since success depends to so great an extent on the application of the proper mechanical appliances.

Puddling, as the members are aware, is the process of eliminating certain impurities from cast iron, whereby its character is sought to be changed from a hard, unyielding, brittle material, to one of a comparatively soft and ductile nature. The operation requires considerable intelligence and excessive labour, and it is the successful combination of these two elements which constitutes the great difficulty, as evidenced by the high wages that good puddlers can command. The difference in individuals of this class is very marked, it being far from uncommon for a bad puddler to cause a loss in weight of say 10 per cent. of material, leaving a large amount of phosphorus in the iron, which in consequence is inferior in quality; whilst a good puddler will, with the same pig, lose only 5 per cent. or less in weight, and succeed in reducing the phosphorus to a greater extent, producing better iron. This is readily accounted for: the former neglects his firing and omits to attend to his firebars, thus creating an intermittent action, more particularly as regards the supply of oxygen by which the iron becomes oxidised or cut to waste. He also neglects to rabble or puddle regularly, so as to bring every particle of the iron into immediate contact with the fettling. The good puddler on the

other hand, by his skill and attention, not only produces good iron from ordinary pig, but in some cases from bad pig also. Experience has shown that the latter class are few and diminishing in number daily.

Although the requirements for good puddling are apparently so simple, manual labour is not to be depended on for this purpose; consequently mechanical puddling has been called into requisition. Sufficient has been established by various workers in this field of enquiry to enforce the conviction that puddling by a revolving chamber is superior as compared with hand puddling or other rabbling, as not only are the yields increased, but the quality of the product is most strikingly improved. The most careful efforts have been made to obtain equal results by hand from like material, but in every case the rotary puddled product was the best; with such facts before them, it is presumed, the Mechanical Engineers will overcome every mechanical difficulty, if it has not already been accomplished.

The several drawings shown in Plates 40 to 43 are for the purpose of giving a general idea of the various arrangements that have been proposed, without entering minutely into their details.

Fig. 1.—*Walker and Warren's*, dated 1853.—The barrel chamber is here placed obliquely, revolving on a horizontal axis, and is heated by an ordinary fire at one end, the flame passing out at the other through a fixed flue.

Fig. 3.—*Maudslay's*, dated 1858.—The puddling or melting furnace is a cylinder caused to revolve on an oblique axis, the flame being deflected into the revolving portion in a line with its axis, and escaping from the same face or end. This appears to be the first occasion on which the heat has been so directed in revolving furnaces.

Fig. 5.—*Tootli's*, dated 1861.—This comprises a drum revolving on a horizontal axis, with a fireplace at one end and a movable fluepiece at the other, which is described as capable of being moved away in any direction for the purpose of enabling the ball to be extracted, and through which the gases escape to the chimney. This appears to be the first time a movable fluepiece

had been proposed to serve as a door and flue; the fireplace was also movable.

Fig. 6.—Also *Tooth's* (Yates being associated with him), dated 1863.—This has the puddling furnace revolving on a vertical axis, the flame passing from a fixed fireplace, and deflected, as in Maudslay's, into the revolving portion in a line with its axis, and escaping out of the same face or end of the furnace.

Fig. 8.—*Danks'*, dated 1869.—This is similar to Tooth's of 1861; it revolves on a horizontal axis having a fixed fireplace at one end, and at the other a movable fluepiece serving as a door and flue for giving admission to the furnace and for the exit of the gases to the chimney.

Fig. 9.—*Sellers'*, of Philadelphia, dated October 3rd, 1871.—This puddling furnace revolves on a horizontal axis, the flame passing from a fixed fireplace into and out of the same face or end of the furnace, similar to that shown in Maudslay's and Tooth's of 1863, except that the drum is horizontal, Maudslay's being oblique and Tooth's vertical. When the puddled ball has to be discharged, the puddling chamber itself is removed from the fireplace or fixed portion of the furnace.

Fig. 10.—*Siemens'*, dated November 5th, 1871.—The furnace revolves on a horizontal axis; the flame passes into it from a regenerative gas apparatus and out at the same face or end, similar to Maudslay's, Tooth's, and Sellers', a door being arranged at the opposite end for withdrawing the ball.

Fig. 12.—*Crampton's Dust-Fuel Furnace*, dated 1872 and 1873.—A is a revolving chamber which is made to rotate on a horizontal axis; the speed can be adjusted to any velocity up to say 10 rev. per min.; B B is the refractory lining; and C C the wheels on which the furnace revolves. D is the movable fluepiece lined with suitable refractory material, capable of being removed when access to the furnace is required; in the case shown in the drawing the fluepiece rests upon three wheels E, which run on iron rails and have screws F on the axles of the wheels for keeping the fluepiece against the furnace. G is an opening in the movable fluepiece, through which the air and fuel are injected. H is the pipe

through which regulated streams of air flow, and which conveys the fuel from the coal reservoir to the furnace through the nozzle I. A plan of this is shown enlarged in Fig. 15, Plate 44; and at K are several partitions in the bend of the injection pipe for the purpose of preventing the fuel and air separating on passing the bend. L is a double-way cock for the admission and exit of the water to the double casing of the furnace; the flow of water is shown by arrows. The water enters at L, passes into the pipe M, and is delivered at the end N into the casing, circulating through the whole casing and making its exit at the end of the pipe O, passing thence to the cock L, and leaving it by the pipe P. The water is then conducted by the pipe P to the fluepiece, entering through a flexible pipe at the lowest point and leaving at the highest point at R. S S are the wearing joints of the furnace and fluepiece directly in contact with the water casing. T is the opening in the fluepiece for the exit of the products of combustion into the chimney, where they may be utilised in producing steam or heating the air, or both.

The coal, which is ground and sifted previously, is brought into a tank U, shown in Fig. 14, by a screw or creeper. In order that the powdered coal may not clog, stirrers V are used, which serve also to bring the coal from the tank to the feed rollers W W. The opening from the tank can be made larger or smaller as required by a sliding door X. The distance between the rollers can be adjusted and the feed regulated with the greatest accuracy by a lever and screw Y; two scrapers clear the rollers. The coal falls through a shoot Z to the air pipe H, into which it is induced by the current of air traversing it from a blast reservoir.

It will be seen that the horizontal drum system of furnace in all the above cases, provided with separate fireplace, operates on the metal in a similar manner.

Fig. 11.—*Mechanical Rabble.*—The mechanical rabble process was suggested at an early date: it consists essentially in substituting machinery for working the ordinary rabble instead of manual labour, thereby reducing the hard work. The drawing shows the rabble operated upon by one of several different mechanical

means. This system, however perfect it may be, leaves the hand work of balling up untouched, and therefore can hardly be expected to be as useful as the revolving drum system, which displaces all severe manual labour.

The principle of the revolving puddling system, as first introduced by Walker and Warren in 1853, has been very generally followed by others in their endeavours to work out the problem.

Tooth's descriptions and specification can scarcely be read without arriving at the conclusion that he at a very early period had made himself acquainted with the difficulties of the subject; he however from various causes failed to reduce his views to practice. He fully understood the importance of the fettling question, keeping the furnace free from extremes of heat and cold. He refers to the movable fluepiece, a very simple device, as a means of obtaining access to the working chamber. Maudslay and Tooth were, it appears, the first to suggest the introduction of the flame from the fire or gas-producing chamber into and out of the same end of the revolving puddling chamber. Tooth had evidently expended much time and thought on this important question, but in adopting the revolving barrel of Walker and Warren he does not appear to have attached very great importance to the necessity of providing mechanical means for producing with certainty the requisite volume and quality of heat, upon which so much depends; he, like many of his successors, directed his attention more especially to the economising of labour. Mr. Menelaus contributed much to the success of mechanical puddling; his extensive experiments, although not successful, taught what not to do, which is the next best to telling what to do.

Without entering into the details of the numerous plans proposed previous to the author's single-chamber dust-fuel system, it will be sufficient to remark that they may all be classed under two kinds: the one, in which the puddling is effected by the revolving of cylinders placed at various angles, containing the melted iron to be operated on; the other, providing mechanical means for working the rabble in the ordinary puddling chamber.

The application of machinery to the ordinary rabble is doubtless a step in the right direction, but the labour saved is comparatively small, since it only relieves the rabbler from a portion of his work, whilst the forehand has still to perform the arduous operation of balling up. The weight of the charge may be increased, but it must always be limited by the power of the forehand to ball it up. The heavier the charge, the greater the labour, the production of gases and heat, and attention generally to the process being in no way lessened; it follows therefore that a portion of the labour only can be saved by the mechanical rabble, and any improvements in other respects in working or heating the furnace are equally applicable to the ordinary furnace.

The revolving system, on the other hand, see Figs. 1, 5, 8, and 9, when heated by gases produced in a separate chamber, enables immense masses to be heated with facility, reducing the labour to a minimum; but equal intelligence is necessary in attending to the regular production, utilisation, and combustion of the gases, and in preventing the coal passing from the fire chamber into the iron in the puddling chamber. Some attach even more importance to these points than to efficient or perfect rabbling.

It may be observed that, when gas is produced (see Fig. 10) and conveyed from a distance, the coal does not enter the puddling chamber, which is an advantage; but in this case also considerable intelligence is necessary in producing and regulating the supply of the gases and air.

Attention may be directed to Sellers' furnace (Fig. 9). The flame enters and leaves at the same face or end, in the direction of the axis of the furnace, the same in principle as that of Maudslay's and Tooth's, shown in Figs. 3 and 6. Sellers describes many ingenious devices for removing the revolving furnace from the fireplace when access to it is required; but the simple plan of Tooth (Fig. 5) for shifting the fluepiece would appear to be better adapted to the rough usage to which it would be subjected in iron works.

If the views here expressed be correct, it follows that the revolving system referred to, with separate heat-producing chambers, can puddle large masses efficiently without severe manual labour,

but still requires as much intelligence in attending to the quality of the flame as in the old system.

In the author's furnace, where the firing is done mechanically, little skill and no exhaustive labour are required. The fuel, in a state of powder, is automatically mixed in proper proportions with air, and injected into the furnace, where it is consumed immediately in contact with the work under treatment, no coal falling into the iron. This cannot fail to be an economical mode of proceeding; the heat is not only more intense than when produced and conveyed from a separate chamber, but the fuel used in heating the ordinary fireplace is entirely saved. The fuel consumed in heating iron does not depend so much on the weight of the iron under treatment as on the cubic capacity of the chambers heated, the loss of heat by radiation being very considerable in all those parts of furnaces where the gases are generated outside the working chamber. From the drawing it will be seen that the whole of the usual brickwork is dispensed with; consequently there is no loss in this respect.

The value of perfect regularity in the flame will be appreciated, as in practical working little if any loss by oxidation is sustained in the weight of the ball as compared with the pig charged. If a ball, after being ready to be discharged, is allowed to remain for two hours in the furnace without reducing the heat, it is rarely that the wrought iron produced is of less weight than the pig iron charged. The furnace has produced from 95 to 104 per cent. of finished $2\frac{3}{4}$ inch square bars, such as are shown bent double cold, from 100 of inferior pig, the bars being re-heated, re-hammered, wash-heated, and rolled off. In the case where the fettling was weighed, 98 per cent. of bars, treated as above, were produced from 100 of pig iron, using 8 cwt. of fettling to the ton. Although these results were obtained in the ordinary working of the furnace, they must not be taken as an average. It is to this peculiar power of regulating the dust-fuel and air that such good results are mainly due.

Assuming that efficient machinery has been devised, capable of effecting the object, the weight of the masses operated upon is

of little importance, and charges of 10, 15, or 20 cwt., or more, can easily be puddled in one piece, limited only by the means for subsequent manipulation of the ball.

It must be evident that in the ordinary course of manufacture by the piling system, as each layer contains a portion of dirt or cinder, this becomes wrapped up in the welded mass; in practical working this cannot be avoided, but is entirely obviated when large puddle balls are properly treated. Many think piling the better process, for the reason that the skill of the puddler can be brought to bear on small portions of the mass, and on the principle that a combination of a number of good parts must necessarily make a good whole; but it is the author's object to show that the material obtained from large homogeneous masses is superior in every respect.

Again, the quality is further improved by the more effective puddling of the revolving barrel, and the consequent better abstraction of phosphorus and other impurities; so much so, that iron equal to the best Yorkshire brands has been made from common Cleveland pig. The specimens shown are the results of practical working, not samples made for a purpose. This system therefore admits of large articles, such as rails, plates, &c., being manufactured in one solid piece, without incurring the risk of flaws arising from the faulty welding of the piles.

If the mechanical arrangement of the furnace involve great wear and tear, and constant supervision and anxiety on the part of the managers, foremen, and men immediately connected with it, mechanical puddling will have to be abandoned, at least for general purposes, however good the iron produced may be.

On reference to the drawings and above description, three notable points of difference between the author's and the other forms of revolving furnaces will be observed.

First.—There is no separate fireplace or gas generator built of brick, and no firebars, these being entirely abolished; there is but one single revolving chamber lined with oxide of iron, forming the gas producing, gas consuming, and utilising chamber.

Second.—The means adopted for the supply of fuel is entirely mechanical.

Third.—The whole furnace is encased in water.

With respect to the mode of producing the heat, the author considers that fuel in a state of powder or minute subdivision affords the best opportunity for its economical consumption, for in that condition a machine can be constructed to feed it regularly into a constant stream of air from a fan or other blower, complete combustion being effected without excess of air, the only necessary condition being that the engine producing the blast and driving the feeder should be kept at one uniform speed. With the machine shown in the drawing (which has been in use throughout the whole series of the author's experiments, extending over six years) this can be easily accomplished, the power of varying the quantities of air and fuel being entirely under the control of the workman. The author believes that neither the ordinary firegrate nor gas furnaces can practically produce combustion so efficiently as dust coal, as the degree of temperature or character of flame is under immediate control, the system allowing that the flame may be lengthened or shortened to suit the various capacities of furnaces, and to maintain an equilibrium of temperature and pressure in all parts of the furnace, a result not so conveniently attained by any other system.

After providing for the regular supply of air and fuel, the next point was to consider how a revolving furnace whilst white hot in the interior, and containing molten metal, could be constructed so as to prevent the contents leaking through a moving joint 3 or 4 ft. diameter, a portion of which would be often 2 ft. below the surface of the liquid metal. To accomplish this, the bad effects of expansion and contraction had practically to be neutralised. The whole apparatus was therefore covered with an annular space, through which cold water is forced to circulate by means of a revolving cock. The means adopted has proved so effectual, that after $2\frac{1}{2}$ years' working the wrought-iron casing of the furnace is in as good condition as when first erected, and still runs as true as a lathe, the joint rings remaining so perfect that the liquid metal is completely restrained from leaking between them.

With the mouth or lip of the furnace, so difficult in other systems to keep repaired with fettling, and on which so much depends, no difficulty is experienced, it being self-fettling in its operation, and the workman has no need specially to fettle this part. If a portion of the fettling be accidentally knocked off, and the plates exposed to the interior heat in the furnace, the circulating water acts as a protection, and causes the melted cinder to chill and accumulate to its normal thickness. On many occasions, in the presence of friends, the last being the visit to the furnace at Woolwich by the members of the Institute of Staffordshire Iron-works Managers, the author purposely detached large portions of fettling, thus exposing the surface of the interior iron casing to the direct action of the heat; and in a very few revolutions the liquid cinder solidified on the bare places, thus re-fettling the furnace automatically.

By these arrangements hard manual labour is entirely dispensed with, repairs are reduced to a minimum, fuel is saved, no smoke is produced, no coal can enter the iron, and but little intelligence is required; and as the furnace is covered with water the men are not subjected to any oppressive heat, in fact in summer the coolest place in the works is near the furnace.

Some attention must of course be paid to the process, more particularly in preventing the formation of young iron, and the balling up too hurriedly. From the extreme simplicity of the operation this may easily happen; young iron has occasionally been produced and not discovered until worked up. This is mentioned, as it must not be supposed that puddling, however perfect mechanically, can be made quite self-acting.

When the greatest economy of fuel is desired, it is advisable to utilise the waste heat in its passage up the chimney, either for generating steam or heating the air on its way to the furnace, or both. In a series of experiments lately made by the author in his furnace, the effect of hot air on the consumption of fuel was shown in a very marked manner. The temperature of the injected air varied in the various trials from 200° to 500°; at 380° not only was the fuel reduced two-fifths, but the furnace was hotter, besides which he was able to use, without inconvenience, very inferior coal

containing 20 per cent. of ash. A furnace with a cubic capacity sufficient to puddle 15 cwt. balls was kept at a welding heat with a consumption of 3 cwt. of coal per hour, as compared with 5 cwt. when the air was injected at the temperature of 60°. The author has not yet used hot air when actually puddling iron put into the furnace in a liquid state; but as the time during which coal is being blown into the furnace is known in other cases to be about 40 minutes for each charge, he does not think himself over sanguine in believing that with 10 to 15 cwt. charges he will be able to reduce the coal as low as 4 cwt. per ton of puddled blooms; with 15 to 20 cwt., as low as 3 cwt. per ton. This is not so surprising as at first sight it may appear, since the gas is generated and consumed in immediate contact with the work under treatment, than which there cannot be more favourable conditions for economising fuel.

In order to show the effects of the two systems of making iron, there are laid on the table a series of samples, consisting of plates and rails, some produced by the best known makers by the usual process of building up small pieces, and others made from one homogeneous puddled ball.

On examining microscopically those which have been planed and polished and afterwards treated with acid for the purpose of showing their internal structure, there can be little doubt as to their relative purity; and the practical tests of bending, stretching, and tensile strains to which they have been subjected indicate superior quality in the homogeneous plates.

There are also samples of steel plates treated in a similar manner, the structure of these and of the homogeneous plates being nearly identical, and showing a clean face; whereas the built-up iron plates show particles of cinder interspersed, the result of imperfect welding, which it is difficult in practice to avoid. There are also samples of steel and iron wire and thin plates made from homogeneous iron puddled from Cleveland pig.

It may be mentioned that all the samples of iron puddled in the revolving furnace were produced from 8 to 10 cwt. charges of inferior cast iron. It is an interesting fact that better results are

not obtained from the high quality pigs; at least the product from the best Swedish and Indian charcoal pig, as well as the best English brands, shows no better results.

The great advance made in the manufacture of steel renders it necessary to consider whether many articles now made of iron will not have to give place to that material; and this appears to be inevitable, unless the old process of making plates and rails as well as many other articles be considerably improved. With regard to plates, the samples exhibited tend to show that as they can be made homogeneous and of good quality from inferior pig, requiring no more labour than ordinary plates, there is some hope left; and with regard to rails, there are many engineers who believe that case-hardened iron rails are more reliable than steel, for if the steel be made sufficiently soft to prevent breakage the wear becomes considerable, but if a good soft homogeneous rail be made from common pig, and case-hardened, the maximum degree of ductility and hardness can be combined.

The case-hardening of rails on Dodds' plan has received some attention. In 1866 Mr. Harrison laid on the North Eastern Railway 10,800 tons of these rails, about 6000 of which are now in use, and are estimated to last four or five years longer, giving a life of nearly fifteen years; a sample cut out last year, originally weighing 82 lbs. per yard, had lost only 2·67 lbs. per yard. The cost of case-hardening was 11*s.* per ton, without calculation for plant. It is believed some difficulty was experienced, caused by the welds opening during the process; but as a homogeneous rail can now be produced, this difficulty can be overcome. In spite of the rapid increase in the use of steel rails, the author still believes in a future for iron, and that case-hardened rails of the quality required can, by the aid of the mechanical revolving puddler, be produced at as low if not a lower price than the ordinary Welsh or Cleveland rails.

To give an idea of the cost of the rails and plates exhibited, the author may mention that some of them have not been subjected to any greater amount of working than common descriptions of rails and plates usually receive, the operations being puddling and hammering into a ball, re-heating, re-hammering, wash-heating, and rolling off.

More than twice hammering does not appear to improve the quality materially.

So much is known on the subject by members of this Institution that it is undesirable to extend this paper, the writer's object being to call their attention to some of the results obtained by puddling large masses, together with the means employed.

The author, in conclusion, remarks that during the whole course of his investigations he has sought criticism. At present he cannot suggest any substantial mechanical improvement in the furnace which has been at work so long at Woolwich; he may have overlooked some essential points, but although on many occasions he has earnestly invited his friends—iron manufacturers, managers, engineers, foremen, and others—when observing the working of the furnace, to suggest improvements which might render it better adapted to withstand the rough usage of iron works, no improvements have been suggested; and he conceives that any serious departure from the arrangements now in use at Woolwich would be more likely to do harm than good. This absence of criticism may have arisen from a sense of delicacy; but the author trusts the members now present will have no such scruples, as it is only by exposing the weak points of any system and discussing them that perfection is attainable.

The author also desires to record his conviction, after a long series of trials, and after testing many hundreds of samples, that homogeneous material is superior in every respect to that built up of pieces, and deserves the most serious consideration on the part of iron manufacturers, more especially since it has come to his knowledge that some of the most extensive and influential users of iron have determined not to employ material made by piling when they can obtain that which is homogeneous; and further, that if mechanical is to supersede hand puddling, and if large masses are to be manipulated, the revolving barrel system must be looked to rather than that involving the use of a mechanical rabble.

SPECIMENS PUDDLED IN CRAMPTON FURNACE.

No. 1.—Plate rolled direct (without being piled) from reheated hammered puddled bloom made from cast-iron scraps containing 0·87 per cent. of phosphorus. The plate contains only a trace of phosphorus. Bent hot. Tested at Crewe.

No. 3.—Plate rolled direct (without being piled) from 8 cwt. reheated hammered puddled bloom cut in half, made from cast-iron scraps containing 0·87 per cent. of phosphorus. Bent and drifted cold from $\frac{5}{8}$ in. to $1\frac{11}{16}$ in. Cut with the grain. Tested at Crewe.

No. 4.—Plate rolled direct (without being piled) from 8 cwt. reheated hammered puddled bloom cut in half, made from cast-iron scraps containing 0·87 per cent. of phosphorus. Bent and drifted cold from $\frac{5}{8}$ in. punched hole to $1\frac{9}{16}$ in. Cut across the grain.

No. 7.—Polished Slab, rolled direct from reheated puddled bloom, and broken cold. Puddled from Cleveland pig containing 1·3 per cent. of phosphorus, the bar containing only a trace of phosphorus. Tested at Woolwich.

No. 9.—Bar rolled direct from reheated puddled bloom, and broken cold. Puddled from Cleveland pig containing 1·3 per cent. of phosphorus. The bar contains only a trace.

No. 10.—Plate first rolled direct (without being piled) from reheated hammered puddled bloom made from Cleveland pig containing 1·3 per cent. of phosphorus. The plate contains only a trace of phosphorus. Flanged hot. The holes drifted hot from $\frac{3}{4}$ in. to $2\frac{3}{8}$ in. and $1\frac{3}{4}$ in. diameter. Tested at Messrs. Fox Head and Co.'s, Middlesbrough.

No. 11.—Puddled Bar rolled off direct from puddled ball. Puddled from Cleveland pig containing 1·3 per cent. of phosphorus, the bar containing only a trace of phosphorus. Tested at Woolwich.

No. 14.—Bar rolled direct from 7 cwt. reheated puddled bloom made from cast-iron scraps containing 0·87 per cent. of phosphorus, the bar containing only a trace of phosphorus. Broken with one heavy blow of steam hammer. Tested at Crewe.

67. A.—Sample Plate 1 in. thick, bent hot with the grain and across the grain.

61. D.—Angle Iron flattened and then bent over cold.

61. C.—Plate, with hole punched hot with key punch out to $4\frac{3}{8}$ in. round; also the other end flattened, bent the reverse way, and flanged.

153. A.—Plate, bent cold with the grain, three times hammered. Piece cut off and etched.

No. 15.—Steel made at Crewe from Crampton puddled iron, which iron was made from cast-iron scraps containing 0·87 per cent. of phosphorus. This steel is part of a 4-ton charge made in Bath.

Nos. 16 and 17.—Tool Steel made in crucibles, puddled from Cleveland pig containing 1·3 per cent. of phosphorus.

No. 12.—Tin Plate made from Cleveland iron containing 1·3 per cent. of phosphorus.

No. 13.—Iron Wire made from Cleveland pig. The small wire is drawn to No. 28 B. W. G.

No. 2.—Wrought-iron Shavings melted in one hour.

Armour-plate Bolt, $2\frac{1}{2}$ in. diameter, broken by falling weights; stretched 50 per cent. before breaking, the area of broken section being reduced to only 30 per cent. of the original area.

SPECIMENS PUDDLED IN ORDINARY FURNACE.

No. 5.—Plate of best Yorkshire iron, bent and drifted cold, drifted from $\frac{5}{8}$ in. punched hole to $1\frac{5}{16}$ in. diameter. Cut with the grain. Tested at Crewe.

No. 6.—Plate of best Yorkshire iron, bent and drifted cold, drifted from $\frac{5}{8}$ in. punched hole to $1\frac{5}{16}$ in. diameter. Cut across the grain.

P.—Yorkshire Plate, etched surface.

H.—B.B. Boiler Plate, etched surface.

S. 5.—Charcoal Iron, drifted from $\frac{5}{8}$ in. hole.

F. F.—Ordinary Common Plates, etched surface.

107. A.—Lamination in boiler plate, discovered by tapping.

107. B.—Plate showing lamination.

A.—Swedish Steel, etched surface.

Mr. CRAMPTON exhibited the series of samples named in the paper, and called attention to the circumstance that in none of these instances had the iron been made by himself; it had all been made by friends who had sent their own iron and manipulated it in his furnace perfectly independently of himself. They had made their own tests, and had forwarded to him their results, the particulars of which were stated in the paper. In all cases these samples had been made from inferior iron, none of it having less than 0·87 per cent. of phosphorus, and the worst—common Cleveland pig—having 1·30 per cent. Some of the tests exhibited were of best Yorkshire plates, showing the opening of the material in the act of bending, and its displacement in driving drifts through the plate; and corresponding tests were shown of plates made from common Cleveland pig, bent double cold, the fracture showing the sound structure and the extension of the iron. The specimen of steel rails had been made by Mr. Webb at Crewe from scrap pig containing 0·87 per cent. of phosphorus, which had been puddled in the dust-fuel furnace at Woolwich by men sent from Crewe for the purpose, and had then been taken to Crewe and made into steel; and the report made of this steel had been most satisfactory. It had been tested against the best steel used for guns and against some of the best steel from Sheffield, and in all cases had been found better than the best pot-steel. Other specimens of plate iron were exhibited, the puddling and heating of which he believed had not taken more than a ton of coal altogether per ton of plate produced; also specimens of iron wire and of tool steel made from Cleveland pig. One of the most remarkable pieces of iron that he supposed had ever been produced was the armour-plate bolt exhibited, which had been broken by impact, a ton weight being let fall on it from a height of $22\frac{1}{2}$ ft. in such a manner as to bring it into tension, and with four blows it broke; it had stretched 50 per cent. in length before breaking—a circumstance that he thought was unprecedented—and the sectional area had been reduced 70 per cent. This bolt had been made from common iron, and such a result he believed could only be arrived at by having a good fettling and a perfectly homogeneous action in the furnace, not only as to the mechanical

rabbling being brought to bear upon all parts of the metal equally, but he considered it was even more important to have the fire perfectly regular throughout the whole operation. He could not conceive any other reason for the production, from the worst of pig, of the best of iron.

Mr. F. W. WEBB said, in reference to the tests that he had made at Crewe, so far as he had worked the iron made in the Crampton furnace, it had been perfectly clean and good in every way; and by analysis he found that the phosphorus was almost entirely eliminated, even from the common Cleveland pig, so much so that there was no difficulty whatever in taking the puddled blooms from the furnace and making good steel rails out of the commonest Cleveland iron, as shown by the samples now exhibited. He would furnish an analysis of the iron in the successive stages of its progress from the pig to the finished steel rails.*

The rough puddled bars that had been puddled in the Crampton furnace at Woolwich had merely been broken up and melted in a Siemens-Martin furnace at Crewe with a little No. 3 hæmatite pig, with the addition of 5 per cent. of spiegeleisen, or of ferro-manganese containing from 40 to 70 per cent. of manganese; and with that there was no difficulty in making an ingot for rolling into a rail. The cost of melting up puddled bars by the Siemens-Martin process

* The following are the particulars of the analyses :—

	Silicon	Graphite	Carbon combined	Sulphur	Phosphorus	Manganese	Iron, by difference	Total.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
Cleveland Pig Iron . .	3·670	2·130	0·520	0·186	0·917	—	92·577	100·0
Crampton's Puddled Iron from same pig	0·078	—	Trace.	0·005	0·055	—	99·862	100·0
No. 1 Hæmatite Pig	3·120	3·820	Trace.	0·004	0·028	—	93·028	100·0
Spiegel . . .	1·420	—	3·150	0·006	0·067	13·120	82·237	100·0
Steel Ingots (produced from above) .	0·014	—	0·330	0·011	0·048	0·060	99·537	100·0

was not much; the wages amounted to about 7*s.* 6*d.* per ton, and then there was about 11*s.* altogether for the other expenses. The cost of making rails by the Siemens-Martin process was about 10*s.* or 12*s.* per ton less than by the Bessemer process. In the working of the Siemens-Martin process at Crewe, scrap was used with the pig iron, because it was very important now to know what was to become of their large quantity of inferior or common iron. If by this process a rail could be produced as good or better than any Bessemer steel rail, a step would be taken in the right direction. At the present time he was turning out at Crewe about 260 tons per week of steel rails made of scrap pig-iron and steel indiscriminately. The whole charge that he had worked in the Crampton furnace had consisted of nothing but common Cleveland pig, without any scrap.

Mr. W. E. Newton congratulated the meeting on having before them a very useful and valuable paper; it was one that had been wanted for some time, giving a history, and, as far as he could see, a pretty complete one—with the exception of one or two minor items, to which he should refer—of the invention of mechanical puddling. The subject was one which had created a great deal of interest, and had received great attention during the last ten or fifteen years. The literature of the subject was diffused over a great number of patents, and considerable service had been done by the author in bringing it within a moderate scope. There were however one or two plans which had not been referred to, perhaps because it was considered they only related to details; but still he thought it was as well if some notice was taken of them.

The first persons who attempted or suggested to supersede the ordinary hand labour of puddling were Messrs. Walker and Warren, whose apparatus was shown in Fig. 1. But, as far as he recollected, that idea had never been carried into practical execution, and he was not sure that a single full-sized puddling furnace had ever been made on that plan. This apparatus consisted of a simple horizontal cylinder, having a lining placed at an inclination to the axis, so that when the cylinder was rotated the melted metal was thrown from end to end and dashed about, in order that it might be

brought into contact with the oxygen of the air and be thereby decarbonised. The next apparatus was Maudslay's; he was not aware that it had ever been carried into effect. It acted upon a somewhat different principle, inasmuch as it might almost be said that it was an ordinary puddling furnace, mounted so as to rotate on a central inclined axis, so contrived that while the furnace rotated on its inclined axis the metal was agitated considerably in order to be decarbonised by the action of the air. There was however no means of balling up, nor did the inventor propose to supersede the ordinary puddling process; his only object in fact was to decarbonise the melted iron to a certain limited extent. Attention had been directed in the paper to the way in which the flame went into the puddling chamber and passed out again at the same face; but he did not think that any of those earlier inventors had paid particular attention to that part of the subject. Something of the same kind had subsequently been proposed in Tooth's later plan of 1863; the only difference was that the circular puddling chamber was not at an inclination, but rotated in a perfectly horizontal plane, and a tool was introduced for the purpose of agitating the melted metal as the vessel went round. It was not necessary for the man to work the tool, but simply to put it into the metal, which was stirred up by the rotation of the vessel itself. He did not think that that apparatus was ever introduced into practice at all, or that there was ever one made. The next apparatus to which he would refer was Tooth's earlier plan of 1861, which was actually carried out in practice, and he had seen it at work several times. It did its work exceedingly well, that is to say, it would puddle and reduce pig iron to a state of wrought iron in a moderately quick time, and save the cost and labour of hand puddling; but it was found that, what with the excessive heat produced and the mechanical abrasion of the metal on the sides of the cylinder as it rotated, it was quite impossible to keep the apparatus in order; and nothing that could be devised ever succeeded in making it stand for any length of time, so that it became practically useless. This apparatus had been tried by Mr. Menelaus, who had spent a considerable amount of time and

money on the subject; and at the Paris meeting of the Institution in 1867 he had given the results of his experience and stated that he had not succeeded in practically reducing the plan to anything like a commercial success. Now the reason assigned for that was that a sufficiently good fettling had not been discovered; and the attention of those who were trying to carry that plan into practice was directed to this point, so as to get a good fettling, and such a kind of brick or lining for the furnace as would not be injuriously affected by the heat and abrasion of the moving melted metal. Still, although a good deal of money was spent and much time was devoted to the subject, this had never yet been done. The next great move was that of Danks, who suggested that it would be necessary to keep the rotating cylinder cool, and showed a plan for doing so, but did not actually do this to any great extent. Curiously enough, although both the difficulty and the absolute necessity of doing so were recognised by him, yet when he came to carry the plan into practice at Middlesbrough he really did not use the cooling apparatus; and consequently, although his furnace succeeded sometimes, it did not answer the purpose to such an extent as to induce ironmasters to take it up.

With regard to the Crampton furnace, there were two or three points in it that differed materially from the inventions which had preceded it. Mr. Crampton was the first who had really recognised that the rotating cylinder must be kept cool, otherwise the desired result could not be practically effected; and he appeared to have done so in the most effective manner. There was no doubt about it that the Crampton furnace was the one invention that had succeeded best in this respect; but he could not agree to the full extent with the plan for generating the heat in that furnace. It was believed by Mr. Crampton to be the best arrangement to carry the carbonaceous matter into the puddling chamber, and to carry with it the requisite quantity of oxygen in the shape of atmospheric air to inflame and consume that carbon; and that was thought by him to be the most economical way of generating the heat. Without doubting the possibility of doing this, he nevertheless thought that was not the best way of carrying out the operation. What was wanted in

puddling iron was, first of all, heat—in fact a neutral flame to reduce the pig iron to a melted state. Then facilities were wanted for introducing a certain amount of atmospheric air with the flame, and to regulate the amount of oxygen so introduced, in order to ensure burning off to a nicety the carbon combined with the iron. When that had been done, no more carbon was wanted, and nothing else was required than to keep up the heat to such a temperature as would allow of collecting the particles of decarbonised iron, and forming them into a ball, and taking this ball out of the furnace. Now it seemed to him that if, after the iron had been partially or nearly decarbonised, uncombined carbon in the shape of coal dust was carried into the puddling chamber, with atmospheric air (which was free oxygen), a very great risk would be run of not effecting the object in view: that is, although it might be effected by clever and intelligent workmen, it was not one of those operations that should be left to ordinary workmen. He would therefore suggest whether it would not be better to generate the gases in another chamber, and burn them so as to get a neutral flame, and then carry that into the puddling chamber; that would give the means of regulating the decarbonising operation to a nicety, and of doing all that was wanted to be done.

With regard to the mode of producing the necessary gases and flame in the dust-fuel furnace, he thought the paper had not given all the information that was needed, as it had not been stated what economy was effected. It was desirable first of all to state what amount of fuel was required by the ordinary process, which was the process the dust-fuel furnace was going to compete with; and then, how much fuel was consumed by this plan to produce a ton of wrought iron. These were statistics which had not been given in the paper, and which it was very desirable to have.

One invention that had not been alluded to in the paper was Spencer's, which had been carried out by Messrs. Richardson at West Hartlepool. He had seen the first puddling machine that was made there on that plan, and certainly it was a most complete failure. The invention consisted mainly in forming a cylindrical rotating puddling chamber by means of a series of iron bars which were bound together by rings, and then the inside was fettled in

the ordinary way to fill up all the cracks. There was no means provided for keeping this cool, and consequently when the puddling operation had been carried on a little time, the whole vessel got so tremendously hot that the iron bars were bent in all manner of shapes, and it became an utter wreck in a very little time. Seeing what happened, Mr. Spencer made some further experiments, and ultimately did succeed in making a machine which acted very well. He had seen it some months afterwards at Messrs. Richardson's works, and certainly it produced some very large puddled balls; but the fault he had to find was, that, the charge being very large, there was no sort of certainty what would be the size of the balls that would be got out of the furnace. Sometimes a ball would be got out weighing 14 cwt., and sometimes one of only about 6 or 8 cwt., with half a dozen little balls of not more than $\frac{1}{2}$ cwt. each. There did not seem to be any means whereby to regulate the size of the balls as was done in the ordinary hand-puddling: still, that furnace did produce very good iron. He quite agreed that, if Mr. Crampton's plan of mechanical puddling could be brought into proper working form, so that any ordinary workman could attend to it, a far better class of iron would probably be produced than was produced in the ordinary puddling process. One point in Mr. Spencer's invention that was claimed as a considerable novelty—although he did not see much in it himself—was this: that, instead of the lining or fettling being supplied in a cold solid state, it was first of all melted, and then poured into the furnace while being rotated, so that the whole of the interior might be coated with this liquid fettling before the iron was put in. Still, he did not think anything had ever been done in the way of keeping the cylinder cool; if it had, it was simply by dropping a little water on it and letting this run down. In the Crampton furnace on the other hand the absolute necessity of doing this had been recognised, and a very convenient and ingenious plan had been designed for accomplishing it; and having himself examined the furnace and seen how this was done, he would suggest that some further explanation should be given of this part of the construction, as he did not think the brief description given in the paper was quite sufficient to satisfy those who had not seen the furnace itself.

Mr. JEREMIAH HEAD said that the question of mechanical puddling seemed naturally to divide itself into, first, the chemical process called puddling, or the elimination of the impurities from pig iron; and secondly, the mechanical appliances by which that was best effected. Some time since, some experiments had been made at the Königshütte Iron Works in Upper Silesia on the process of puddling in an ordinary furnace, and the period of puddling from the cold pig iron up to the finished wrought iron was divided into certain stages or intervals. At each stage a sample of pig iron was taken out, and also a sample of the fettling into which the impurities were gradually passing. These were analysed by Dr. Kollmann of Oberhausen, and the results were published in the Annales Industrielles, and afterwards copied into some of the English scientific journals. These results he had drawn out in a geometrical form in the diagrams exhibited (Plates 45 and 46), in order to show the process exactly as it went on; Plate 45 gave the analyses of the iron, with enlarged details of the impurities, and Plate 46 of the fettling. The vertical lines represented the nine or ten different periods when the analyses were taken; the times of observation were given, lasting from 10-23 a.m. to 12-42 noon, and corresponding in both cases. At the top of each diagram was shown what was happening in those intervals; the 1st vertical line in Plate 45, for instance, represented the proportion between the iron and the different impurities in the grey pig dealt with; the 2nd, when it was melted in the puddling furnace; the 3rd, when it had been somewhat longer in a melted condition; the 4th, when some of the solid grains developed in puddling began to appear; the 5th and 6th were in the period of decarbonisation; the 7th and 8th, when the metal was coming to nature; and the 9th, when it was in the shape of puddled bar. Each of the impurities was also shown by itself in Plate 45 in a subsidiary diagram with a datum line, so that they could be studied separately, while the general diagram showed them all combined together. Taking them separately, and beginning with the phosphorus, it would be observed that in simply melting the pig the phosphorus was reduced by about one third, and its elimination

went on pretty uniformly from beginning to end. The second impurity was the sulphur, and the pig used seemed to have been remarkably free from sulphur; there was very little in it, but what there was had gone pretty steadily out from beginning to end. The third impurity was manganese, of which nearly half disappeared simply in melting; then it seemed to halt a little, but afterwards went quicker. The fourth was silicon; and it was remarkable that in the melting—before any isolated grains of iron even began to appear—most of the silicon was gone. The next was carbon: it would be seen that when almost all the silicon was gone, no carbon whatever had disappeared; on the contrary the proportion of carbon was apparently increased, because some of the other ingredients had gone. Up to the time of the isolated grains having appeared, and the beginning of the period of decarbonisation, the carbon was not sensibly diminished; then it went quickly out, down to the end of the process.

Now on referring to the other diagram, Plate 46, representing the analyses of the fettling, it would be perceived that, just as these different impurities decreased in the iron, so they increased in the fettling. The darker shade in all cases showed the elementary substance itself, and the lighter showed the oxygen combined with it to form the oxide. It would be seen that, as the phosphorus disappeared from the pig in the melting, so it increased in the fettling; there was a certain amount of phosphorus in the fettling to begin with, and on the whole there was more in it by the end of the process, with many intervening ups and downs, than at the beginning, and corresponding with the smaller amount remaining in the iron. Then there were two impurities—lime and alumina—which did not appear to be in the pig, and therefore might be supposed to have been in the original fettling. It was seen there was nearly as much lime in the fettling at the end as at the beginning; therefore that probably had had little or no effect. The same with the alumina; it had been in the fettling originally, and had continued in it throughout, having had hardly any effect. Taking next the manganese, as this quickly got less in the pig at the beginning, so it quickly got more in the fettling; with many intermediate ups and

downs it was more at the end in the fettling than at the beginning, whereas in the iron it was very considerably less at the end. Of course the actual amounts of the several substances in the iron could not be compared with those in the fettling by a comparison of these different diagrams, because it would be requisite to know in each case the total weight of pig iron in relation to the total weight of fettling in contact with it, a question which the diagrams did not take cognisance of. The silicon, which disappeared so quickly from the iron in melting, was seen to have increased at the same time in the fettling; and then after several ups and downs it was somewhat more at the end than at the beginning. With regard to the iron in the fettling, it existed in two forms, peroxide and protoxide; most of it was in the protoxide. There was not really, as would be seen by the diagram, very much chemical difference between the two, the peroxide only containing half as much oxygen again as the protoxide. However it was rather curious how the iron in the fettling seemed to change about from one to the other during the process; at first it was seen how rapidly the change went on in the simple melting, peroxide having disappeared and protoxide increased, showing that the iron was changed from one form to the other. After various vicissitudes it was seen that there was rather less peroxide at the end than at the beginning, and a trifle less protoxide, but there was not very much difference: showing that some had been reduced, and had probably gone to correspond with the increase of iron that there was in the product obtained, and so to swell the yield. To view the matter in this way was a considerable help to himself, and to any who had not been brought up as analytical chemists; and he thought it might perhaps be acceptable to the members to have it thus brought before them.

Reference had been made in the paper to the high wages paid to good puddlers. Now at the present moment he did not think that puddlers were overpaid. The rate of puddling grey iron was 8*s.* 3*d.* per ton; if a man got all he could do, if he got the full number of days per week, after he had paid his under-hand, and after he had got his prize money of 6*d.* per shift, he could not make more than

about 35*s.* per week; which did not seem to him excessive. But inasmuch as under-hands were extremely scarce, at least half the puddling furnaces in the Cleveland district were worked "level-hand," that is, two puddlers worked each furnace and divided the proceeds; and if they worked level-hand and got the full number of heats, they could not get more than about 30*s.* each per week. Of course they did not always get the full number of heats; therefore he did not think that the puddler, considering what he had to do, was an overpaid workman. The ironworkers who were often overpaid were the rollers, heaters, and certain contractors: the plate rollers in his own works were at present earning each about £8 clear per week under favourable circumstances, that is, when they got a good fair average quantity; that was what they earned in one of the two plate mills, and in the other they got about £4 per week.

The increase in the yield of iron resulting from the skill of the puddler had also been referred to in the paper. That was true to a considerable extent, but not altogether; the increase of yield resulted in some cases, as he had tried to show, from the fettling. In an ordinary puddling furnace any good puddler, if supplied with plenty of fettling of good quality, could bring out more iron than was put in as pig; but it was true, as stated in the paper, that practically the yield was from 5 to 10 per cent. less.

With regard to the mechanical rabble, at the present time in the Cleveland district there were several furnaces on that principle at work, and they seemed on the whole to do better than the ordinary hand-puddling furnace; they puddled larger heats, and seemed to be able to produce good puddle bars at a somewhat lower price. They were also preferred for other reasons; the transition from an ordinary puddling furnace to the mechanical rabble was not so great as to a rotary furnace like that described in the paper. Then again the scarcity of under-hands, and the habit of the men to work level-hand, seemed to be rather well adapted to a puddling furnace with the mechanical rabble: four level-hands working large heats in a double furnace could do better than he had shown they could do in an ordinary single puddling furnace; and

consequently the mechanical rabble was perhaps more in favour with the men.

With regard to the Crampton furnace itself, he had now had some experience with it at his own works during the last $2\frac{1}{2}$ years, and had watched it closely at Woolwich 2 years before that. He was of opinion that without doubt the requisite heat could be got with powdered fuel of good quality; there was also no difficulty whatever in producing that powdered fuel. It was usually necessary to dry the fuel before grinding, otherwise, coming as it commercially did in trucks and being liable to exposure to rain, it might go into a pulp; but if it was dried, and then well ground, which could be done by proper appliances, there was no difficulty in getting the required heat. But he thought perhaps the labour and expense required in feeding the powdered fuel into the furnace had been underrated in the paper, in which it had been stated that the furnace could be fed with fuel entirely by mechanical means, without any labour. That, strictly speaking, was quite correct; the coal required to be ground, and a miller was therefore required to look after the stones and other machinery for grinding and sifting it; and owing to the state in which the coal was apt to come in from the trucks, some labour was required for drying it. Supposing a full forge of eight furnaces were at work, he thought that, including the miller and driers and so on, at least four men would be needed; at his own works he had not succeeded with fewer yet, so that it was a question whether—as in an ordinary puddling furnace the coal was simply tipped into the bunkers and shovelled into the furnace by an under-hand—those four men with the eight Crampton furnaces ought not to be considered as standing against one man to each ordinary furnace.

With regard to homogeneous iron, of which a great deal had been said in the paper, he did not think there was any advantage in representing anything under too favourable an aspect, because the object was, if there were difficulties, to discuss them, and perhaps some one would then be able to remove them; and having devoted a good deal of money and time to the success of this furnace, he felt anxious that all difficulties that remained should be solved. There

was no doubt that difficulties of lamination in the iron were most apparent in rails, in plates intended for flanging, and in angle-irons intended for being bent; but lamination he had never found to be any very serious detriment to plates used for shipbuilding purposes or bridge building, or even for the shells of boilers where the iron was not exposed to the action of the fire and was not flanged. Under such circumstances the lamination very rarely became apparent in any way, so far as his experience went; and with regard to plates by far the largest consumption was for bridge and shipbuilding purposes, where they were not flanged at all. The making of iron in solid blooms was not a new process, it had been tried at various times; and the puddled-bar process had been considered as an improvement upon it and as superseding it, rather than the other way. But it was possible of course that with better appliances that order might be reversed, and the solid blooms might be reverted to. The sample exhibited of plate iron, which had been flanged hot and drifted hot, had been made under his directions at his own works. The Cleveland pig from which it had been made was made at the Carlton Iron Works by Mr. Briggs, by whom it had been sent to Woolwich and puddled in the Crampton furnace; it had then been sent down to himself in the shingled bloom, reheated, rehammered, and rolled into a plate. The two holes in the sample were originally about $\frac{3}{4}$ in. diameter, and were drifted hot to their present sizes, $1\frac{3}{4}$ in. and $2\frac{3}{8}$ in. diameter; it was seen they had stood remarkably well, and better iron could not be desired for any purpose. But it must not be supposed that the whole plate out of which that sample was made would have done that; the plate had various defects on the surface, and the sample piece was free from those defects. This showed that the quality was in the iron; still the difficulty of getting large plates free from defects had not yet in his opinion been altogether surmounted. A plate was a very difficult thing to make free from all defects; if there was anything raw in the iron in any way, it was sure in the rolling to come out somewhere on the surface and spoil the plates. A large plate was rejected for a very small defect, although the quality of the iron might really be good; that was probably the principal difficulty to contend with, and he did not

think it had yet been fully surmounted. In the rolling of these plates they did not roll exactly as ordinary iron did. They seemed to roll very beautifully at the time, almost like lead; but when they were cold, certain defects were apt to be found which were not seen when the plates were hot; and the iron was what was called of a dry nature, that is, there seemed to be less cinder in it than there was in ordinary iron. It was likely that these difficulties would be overcome after a while, but they were not completely overcome yet; and he thought it was as well to name them candidly, in order that those experienced in such matters might be able to make some suggestion. It had occurred to him that very likely the great tendency of defects to come out to the surface when iron was rolled out into thin flat pieces was what had early suggested the puddled-bar system as superseding the bloom system. It had been said that if the iron could only be rolled thin enough the impurities would be brought out to the surface, and then there would be an opportunity for rejecting defective pieces. Also when it was put into the form of puddled-bar, bars could always be selected for the top and bottom of the pile which were free from defects, and this ensured a good surface; any piece could also be rejected that might have any very manifest impurities in it.

Warning was given in the paper that it must never be expected to get the process of puddling made entirely self-acting; and in this he thought the author was wise, as also in inviting free discussion of the subject. With regard to the various plans for mechanical puddling that had been referred to in the paper, he was much struck in the case of this subject, as in the case of many others, with the great number of minds that had been working upon it at various times. Nothing of this sort was the product of one mind; a great many had really built it up gradually. The list of inventors given was by no means complete; and there were others unknown by that name, yet who had laboured assiduously for a long time, and had materially contributed to the development of rotary puddling.

Mr. E. H. CARBUTT considered they were much obliged to the author for bringing this subject before the Institution, and he

thought a lesson might be drawn from it for the future; for he believed this was the death-knell of the wrought-iron trade, and that in a few years' time the general use of wrought iron would be a thing of the past, and that steel would be used for every possible purpose. That impression had been confirmed by the remarks of Mr. Head, who had stated that there was a very great difficulty in getting a good plate made from puddled-bars, and that plates so made were liable to have many defects and flaws.

From his own knowledge of the appliances that were used in manipulating the large balls of iron that were rolled into puddled-bars, he was convinced that at present at any rate the right way of dealing with them had not been arrived at. The only way in his opinion was to do what had been described by Mr. Webb—remelt the puddled-bar in a bath of cast iron in the open hearth of a furnace heated with gas or coal, and make it into steel; then it could be cast into an ingot small or large, and could be manipulated thoroughly. At the present time a puddled-ball was obtained which contained a great many impurities, and there was no possible means of manipulating it so as to get rid of these. The great thing which had kept back the use of steel was the action of the Board of Trade in not allowing bridges and ships to be constructed with steel plates, which could be proved to bear a greater tensile strain than iron plates; if that difficulty could be overcome he believed that the substitution of steel would be a certainty. Steel was already used largely, and would be used still more largely, for rails, axles, and everything connected with railways; and he believed the practice of Sir Joseph Whitworth would be followed in the use of steel for guns, and that in the future all guns would be made of steel. The governments of Germany and Russia were having steel guns, and he believed this country was now placed at a disadvantage in that respect.

It had been shown in the paper now read how by means of the Crampton puddling furnace impurities could be eliminated out of cast iron, and a spongy mass obtained that could be converted into steel at a cheap rate. By that means it would be possible to utilise all the pig iron made on the East coast of this country, and to make

steel of it, and the pig iron on the West coast could be made into steel by the Bessemer process; so that all the raw material in England could be utilised, with far less wear and tear upon the men, and with better results in the end.

Mr. BERNARD P. WALKER remarked with respect to the first revolving puddling furnace, referred to in the paper, that he was the inventor, and it was actually put into operation on a small scale with a $\frac{1}{2}$ cwt. charge, and results were arrived at which corresponded with what had been stated in respect of the working of subsequent plans for revolving furnaces. The iron produced was found to be almost invariably cold-short, the same as had been the case in the trials afterwards made by Mr. Menelaus; every now and then some pieces were got that could be rolled out, and he had some pieces still that had been rolled out into sections equal to $\frac{3}{8}$ in. round iron. The experiments had been carried on only on a small scale for pecuniary reasons; the pig iron had been made at the Lays Iron Works near Stourbridge, from East Worcestershire and Staffordshire ore. The lining or fettling adopted for the puddling vessel had been suggested by the late Mr. S. H. Blackwell, who had been present at the experiments, and it consisted of hæmatite red ore from Cumberland mixed with Stourbridge burnt fireclay; and that gave the best results that had been attained. He had then been preparing, also at Mr. Blackwell's suggestion, to use gas for heating the furnace, when he heard of the experiment which had been tried by Mr. Tooth, with whom he soon afterwards put himself in communication; but the matter had fallen through, and nothing had been done for a long time, he supposed on account of the state of the patent law, until the whole interest in the invention was made over to the Dowlais Iron Company. He thought it might be interesting to the members to know that those earliest experiments had actually been tried with a certain amount of success; and in common with every one else he felt greatly indebted to Mr. Crampton for so far maturing this original invention of his own; he certainly trusted that it was the commencement of an important era in the iron trade of this country.

Mr. C. COCHRANE asked whether Mr. Crampton had dealt with the question of dividing up the large ball of iron produced from his furnace into smaller parts, so as to meet the necessities of such districts as that of South Staffordshire. Two years ago he had himself made an effort to introduce the system into Staffordshire, and the main objection by which he had been met was that the ball was so large that it was impossible to handle it in any of the existing ironworks, which contained no machinery competent to roll such large masses. That of course meant that if the apparatus was to be adopted in that district, and the ball was to be of service at all, it must be divided up; otherwise there would have to be a sweeping away of the whole of the plant of any works where it was proposed to adopt this system of puddling. He believed Mr. Crampton had some idea of devising a means of dividing up the ball; and he should be glad to know whether he had done so. In Middlesbrough, where there was a much superior plant to that of Staffordshire, it was looked upon as highly objectionable to have to divide the ball up even into two, which was done by cleaving it under the hammer before passing it on to the rolls.

Mr. S. Z. LLOYD asked whether more detailed information could be given as to the cost and quality of the fettling used, as compared with the cost of the ordinary fettling in the Cleveland district. The quantity had been stated to be 8 cwt. per ton of pig, but the quality had not been mentioned. Some information which would give the means of ascertaining the comparative cost would be valuable.

Mr. E. A. COWPER thought they were much indebted to the author for bringing forward such a comprehensive paper, not dealing so much with the actual use of his own furnace as with the great question of large masses of homogeneous metal being puddled in a perfect manner and brought out in good condition. He thought the production of these large masses was more important than the reduction of the cost of puddling; because in making large plates and large structures of all kinds, homogeneous masses must be produced to obtain perfection of material, but he was afraid the

same perfection that was already attained with steel could never be obtained with iron, unless the metal was thoroughly melted. He thought that mechanical puddling furnaces were of immense importance to the South Staffordshire district, because, although unfortunately a very large quantity of pigs puddled in the district came from a distance, there would always be a demand for South Staffordshire iron puddled in the district, to make the peculiar and varying qualities of wrought iron required to stand the great variety of contortions and strains put upon it by manufacturers in that neighbourhood. This he thought would always cause puddled iron to be made in that district to a large extent, and therefore he thought the Crampton furnace was of especial importance to the ironmasters and manufacturers. The Staffordshire boiler plate was a good thing when something better could not be got; though of course the Yorkshire plate did surpass it to a certain extent, and the Staffordshire ironmasters would be glad to be able to make the quality of the Staffordshire up to the Yorkshire. He had seen the product of the Crampton furnace at Woolwich from time to time, and he must say the Middlesbrough pig even had turned out wrought iron very nearly equal in quality to the Lowmoor. He was not referring to a single bar, but he had picked up different bars and broken them with a sledge hammer, observing how they broke, and the metal had been superior to anything made from Middlesbrough iron by hand. He did not mean to say that no other rotator could do the same, as all rotators that would work made better iron than was made by hand. In the Crampton furnace the whole of the iron was treated equally and all brought to nature at one time, instead of a little bit at a time as was done by hand. The iron knew when to ball up better than the puddler, and all that had to be done was to retard it a little and prevent it from balling up too quickly and producing the iron too "young." If the balling up was done at the right time, the fine-grained quality was obtained which was seen in Lowmoor iron, and which was very advantageous in tyres, axles, boilers, and other constructions.

With regard to the mechanical puddling furnaces themselves, he thought that the early failures of rotators arose very much from

the fact of trying to make a fettling or lining that would stand. He thought Mr. Danks had been one of the first to face that difficulty boldly, by determining not to care if the fettling did not stand, but deciding that if iron could be got out of the oxide of iron used as fettling it would pay, and more oxide of iron could be put in to go on with the puddling again. The Danks furnaces had accordingly been fettled with oxide of iron, and more iron was brought out than the pig put in; and that way of working paid, and would pay. It was a question of supplying good fettling; no brick lining would ever stand the wash of the liquid iron in the puddling vessel unless covered by a coat of fettling. Undoubtedly that was the right way of making a furnace work, constantly "basting" it with fresh fettling, and letting this stick to the sides by cooling. Mr. Tooth's puddling chamber as he understood had been cooled to a certain extent with a sprinkling of water on the outside, and the difficulty had been faced more boldly by Mr. Danks, who had employed a pretty good sprinkling, but still not enough. Still the Danks furnace had not succeeded in doing so much as had been expected of it by those who had tried to drive it and to get as much work out of it as possible, with the idea of reducing working expenses: the result being in one or two cases that the expenses were doubled by the furnace being torn to pieces by the heat. Some of those furnaces had been treated in a most unfair manner in this country; great pressure had been put upon them, so that the fire had been blazing out all round the joints and cutting the furnace to pieces; whereas if it were kept cool it had a fair chance of working well. He was not speaking from his own opinion, but from what had been done by others. Mr. Robert Heath, M.P., Stoke-upon-Trent, had been working with Danks furnaces from the first and treating them moderately; it was not thought that much money was saved, but a better quality of metal was made. He had lately come across some of Mr. Heath's plates, and found that they were rising in estimation generally.

The question of cooling the furnace had been faced in a very complete manner by Mr. Crampton, who had a close water jacket on the outside of the furnace, which consequently kept absolutely in shape; it had been running on the same rollers for several

years, and had never been buckled out of shape. Mr. Crampton had certainly made a rotator that would work well, the wear and tear being very small. With regard to the powdered fuel, he did not feel quite competent to give a decided opinion on it, because he had some misgiving about the cost of grinding. As to the fettling he should be glad if Mr. Crampton would give a little more information. All the rotary puddling furnaces required good fettling; they would not work well with bad fettling. Fettling was wanted with more iron in it than common fettling had; bulldog had not quite enough, it contained too much silica, and was too fusible. If ordinary ball-furnace cinder were melted down, with a certain quantity of scrap-iron, good fettling containing the required proportion of iron could be made.

Another point was with regard to cutting up the ball. Balls had been cut up in a satisfactory manner by a large pair of cutting shears bent at the end like curved scissors, that were bent down and inserted in the furnace, and the oval roll or ball of metal was nipped in half in the furnace at a time when it was hot and soft like wax. He did not think there was much difficulty about this, and if it was wished, the ball could be cut small and piled afterwards; it was a great pity to pile it, unless it was necessary. He thought it might be expected with confidence to get balls made up to 10 cwt. very clean, and with such heat in them that when properly manipulated the cinder would come well out. He had seen bars rolled down to about $2\frac{1}{2}$ in. square, from an ordinary ball that had been puddled in the Crampton furnace, and when cold it had been folded down close under the steam hammer without the symptom of a crack; and there was less cinder and less dirt in them than in the bars that were used for gun coils by the government, as was seen when a bar was planed half away. He believed it was for the purpose of making these bars for gun coils that the Crampton furnace was now being taken up by the government; he hoped there would soon be half a dozen at work, making these long bars from 10 cwt. balls. A very clean ball he thought would be obtained from the furnace, comparatively free from cinder, and very much like the Lowmoor quality; this had

been done, and he did not see why it should not be done every day. The Crampton furnace required less skill, less highly paid labour, and less amount of labour than the ordinary puddling furnace. He believed that the iron of the South Staffordshire district would be greatly improved if this furnace was adopted.

Mr. E. H. CARBUTT, referring to the plates rolled by Mr. Heath, which had been spoken of, said that at those works the metal was made into puddled bars and then piled for rolling, not made in one mass.

Sir J. WHITWORTH remarked that if the tensile strength were given of the various specimens exhibited it would add much to their interest. The ductility in the specimens shown spoke for itself; but to judge of the proper value of the material its tensile strength should be stated. In any piece of iron and steel there were three things wanted to be known:—was it sound; what was its tensile strength; and what was its ductility.

Mr. A. PAGET thought a considerable point as to the probability of the commercial success of Mr. Crampton's plan was the production of wrought iron in the form of a spongy mass, from which steel could be made. He should be glad also to know whether with that system there was not ample heat going up the chimney from the puddling furnace to do both the drying and the grinding without any cost whatever for heat or power. He thought, when the author had time to turn his attention to that point, he would be able to show beyond doubt that the coal could be both dried and ground without a farthing's cost for power or heat.

Mr. F. J. BRAMWELL hoped that Mr. Head, who had devoted so much attention to the Crampton furnaces, having had them $2\frac{1}{2}$ years under his observation, would give a little more information respecting their working. He understood it was necessary to take into account the cost of the miller and of the drying of the coal that had arrived by railway; and he should be glad to know whether that drying was

preparatory to the grinding. He further wished to ask, what was, according to Mr. Head's experience, not in a special trial but in fair working, the quantity of coal per ton of puddled-bar produced; and what was the yield, with equal fettling, in this furnace as compared with hand furnaces. He would also ask, as the analyses of iron and cinder in an ordinary puddling furnace (worked by hand he presumed) had been laid before the meeting in so intelligible a shape by means of the diagrams exhibited, whether similar analyses had been made with iron and cinder in a Crampton furnace. In that way perhaps it might be possible to form some opinion why it was that the Cleveland pig, which in the ordinary mode of puddling did not give iron of very excellent quality, was apparently, when treated in one of these furnaces, competent to make such specimens as were here exhibited, that could be cut up and used successfully for steel purposes, as described by Mr. Webb. If those results were obtained, it would be very instructive to know why it was that the puddling mechanically should be so far superior to that done by hand, if it were so; and he supposed it must be so, or the products exhibited would not be obtained. He should be glad to know Mr. Head's opinion about laminated plates, whether he merely thought that such plates were generally good enough, or whether he really preferred laminated plates to homogeneous plates; also whether, if he got a large puddled-ball of 10 cwt. and wanted a 10 cwt. plate, he would cut up the ball and pile it, or make the plate direct out of the single ball.

Mr. Crampton having said that care must be taken to prevent the formation of young iron, he hoped he would also say how that was to be prevented.

With respect to Mr. Carbutt's observation about the use of steel being held back by the action of the Board of Trade, Mr. Carbutt was secretary to the committee of the British Association which for two years had urged the Board of Trade with their representations, without much effect at first; but at last they had become so troublesome that the Board of Trade had appointed one of their own officers, Captain Tyler, to meet Mr. Barlow, the Chairman, and Sir John Hawkshaw to discuss the question; and he hoped that after

the return of Mr. Barlow and Sir John Hawkshaw from America, and after the lapse of sufficient time for discussion and then a further time for the department to decide, a determination by the Board of Trade would be arrived at, which would take away from the steel manufacture of this country the stigma now resting upon it in not being recognised as producing a superior material to iron. It appeared that the dictum of the Board of Trade had been based upon some experiments made nearly twenty years ago with steel that had been made in puddling furnaces without fusion; and those experiments had been suffered to cast a slur upon steel made by fusion processes. As however a strong pressure had been brought to bear—thanks to the British Association, for it had been by the action taken at Bradford that this committee had been originated—he believed a good result would be obtained.

Mr. Jeremiah Head replied that the drying of the coal for the Crampton furnace had to be done before the grinding, the fact being that the coal came perhaps twenty miles by railway and often wet; there could be no reliance upon its being dry, and it would not do to grind it in a wet state. There must be men ready to spread it out on the drying floor if required, and he fancied from what he had seen that drying would generally be required. The actual fuel used for drying was stated by Mr. Crampton to be the ashes; at his own works at Middlesbrough it was the ashes from the other puddling furnaces that was used, so that there was not much expenditure for the fuel for drying, the expense being merely for tipping; but when the coal was tipped down on the drying floor it often happened that some of the lumps had to be broken up; it had to be spread out and collected again and fed into the elevator for carrying it into the mill; and of course the fire had to be kept going. That was the labour that he had referred to as attendant upon the drying of the coal.

With regard to the statement that a good puddler with an unlimited quantity of good fettling could bring out at any time more iron than he put into the furnace, it was quite true that the Crampton furnace did generally, when it was working well, enable a man to bring out more than he put in. So far as the present

experience had gone with the furnace at his own works, the yield amounted to about 6 per cent. increase over the weight of the pig charged, and at Woolwich it was about the same. But it was found necessary to use better fettling for these furnaces than for ordinary furnaces; a good deal was due to the superior fettling, and there was no doubt that the fettling which had generally been used in the Woolwich furnace was very good. If good fettling were used, and plenty of it, a better yield would be got; if not, the result would suffer in another way. As yet no natural ore that was easily accessible in this country had answered the purpose of fettling these rotary furnaces properly; the fettling must be made either from mill furnaces with cinder bottoms, or it must be melted in the ordinary puddling furnaces from cinder, slag, and bits of burnt iron, which were always produced about ironworks, and even sometimes a certain amount of mill cinder off sand bottoms, but that must be freshened up by the addition of scrap iron. The fettling thus obtained must be reduced to a homogeneous condition for the puddling furnace, for which purpose it must be previously melted, and the melting took a deal of coal. Scrap iron was about £3 per ton, and as far as he could see there was not much chance of making good fettling in that way, suitable for the Crampton furnace, under about £2 per ton; the best mill-tap cinder was not to be bought at any price for the purpose.

As to how it was that Cleveland pig treated in this way could produce such specimens of iron as those exhibited, and could not do so in an ordinary puddling furnace, he could only say iron was iron, and if it did not behave as iron ought to do, it was on account of the chemical impurities with which it was allied. If the impurities could only be got out of it, it did not matter where it was treated or how; the iron then did its duty. There was no doubt that this rotary furnace, by the steady manner in which it worked, and by bringing a large surface of good fettling in contact with the impure iron, did eliminate the impurities to an extent which it was difficult to obtain with any regularity in an ordinary puddling furnace. He could not say that in an ordinary puddling furnace, with picked material and picked men and carefully watched,

iron like the samples exhibited might not be made in small quantities; but that was not what was wanted, but on the other hand large quantities and uniform quality.

With regard to lamination, the remarks he had made had simply been in reply to what had been said about the great fault of lamination, which was very manifest in rails, because after the traffic had run over them a certain time they began to split into fibres, and to peel off; and it was manifest even in the flanging of plates, because in the very act of flanging it was seen that the plates began to laminate; it was also shown in angle irons, which would split off in the line of the rivets. But in the shell plates of boilers as ordinarily made it was rarely that any lamination was seen to be produced; it did not appear in the construction or afterwards; and in ship building it was the same. Ship building and shell plates of boilers were the work for which the great majority of iron manufactured in the form of plates was applied, and the objection of lamination was but little felt in those cases.

In reply to the enquiry about making a 10 cwt. plate from a 10 cwt. ball, if he could have the plate rolled out of a single ball he should prefer it; but in the present state of knowledge he doubted whether he could not get a better plate by cutting the ball up and piling it than he should get by rolling the plate out of a single ball. In Belgium there were a large number of strips rolled in universal rolls for the tops and bottoms of girders, not sheared sideways but rolled as broad bars in a universal mill; how little ill effect the piling system had was shown by the fact that those were all piled. The tops and bottoms of the piles were made of a number of bars put sideways together, and in the finished bar it was possible sometimes to trace the weld, but practically this did not seem to interfere with the soundness; there was no difficulty in getting sound tops and bottoms.

The question of the weight of coal consumed in the Crampton furnace per ton of puddled bloom produced was one that he could not yet answer from practical experience; he had not had the furnace sufficiently long permanently at work, but he had watched the furnace at Woolwich and believed at present it was working with

about 3 cwt. of coal per hour with a heated blast, and about 5 cwt. when the blast was not heated; those were the figures given by Mr. Crampton in the paper.

As to the analyses of the iron and the fettling from an ordinary furnace, of which the results were shown in the diagrams that he had exhibited, he had not as yet made any experiments with the rotary furnace as complete as those, but he hoped to make a similar series before long, and would communicate the results to the Institution.

Mr. E. A. COWPER suggested that analyses would be desirable of the cinder that came out of the rotary furnace and the cinder that came out of the hand furnace, in order to see what good these cinders had done, because iron that came out of the rotary furnace was better than iron that came out of the hand furnace.

Mr. JEREMIAH HEAD said he had not yet analysed the cinder that came out of the Crampton furnace; but he knew pretty well what came out of an ordinary puddling furnace, and it varied of course very much according to the impurities in the iron.

Mr. T. ADAMS remarked that Mr. Crampton was not the first engineer to use dust fuel, for in 1868 dust-fuel combustion had been experimented upon by the American government, at Boston, where he had seen it at the time. In that case the coal was not ground by the primitive method of revolving stones, as for the Crampton furnace, but was fed from a hopper into a centrifugal fan or disintegrator, into which air entered at the two sides. So powerful was this machine that it ground up stone into dust. That plan required no expense of labour for feeding the furnace, the disintegrator being driven by machinery, and delivering the pulverised coal direct into the furnace; but unfortunately for the system of combustion, which was bad, the dust collected at the further end of the flues, beyond the furnace, was found to contain 38 per cent. of pure carbon which had never entered into combustion so as to be fully consumed, as it would have been if the combustion had taken place

in the usual way by distillation, that is, by putting the coal in a Siemens furnace where there was time for it to be first distilled into a semi-liquid state and then into a gasified state, when it would be in a proper condition to enter into combustion. As the coal fell down from the hopper the fan sent it immediately flying through the furnace before it had time to enter into complete combustion. The coal was reduced by the disintegrator to something like the size of rough flour; but when it was collected at the further end of the flues it had swelled to something like the size of a pin's head.

Mr. A. SHANKS mentioned that he had sent over from Calcutta a small quantity of Indian charcoal-pig iron, which had been treated in the Crampton furnace at Woolwich, and the tensile strength of the product obtained was about 24 tons per square inch after stretching about 30 per cent. It was very good iron, and very easily worked in the furnace. He had watched this system with great interest, because if iron was to be made in India it must be made by a mechanical process, the native workmen not being strong enough to manipulate the puddling process by hand.

Mr. C. W. SIEMENS said he could entirely endorse the remarks that had been made by Mr. Head; the question of mechanical puddling was mainly one of fettling, and if fettling of sufficient resisting power could be obtained in any quantity, he had no doubt that a furnace such as that of Mr. Crampton would produce very excellent results. He hoped that this question of fettling would reduce itself to a mere question of expense, which would very likely be compensated by advantages of great importance. Amongst the diagrams exhibited of other mechanical puddling furnaces was one representing his own plan of 1871; and having directed his attention to rotary furnaces for a number of years, his object had been rather to go in a short road from the ore to the bar than to accomplish the ordinary process of puddling. In the neighbourhood of Birmingham he had some furnaces at work in which malleable iron was produced from the ore direct; and the furnace which he employed for the purpose, and which was represented in the diagram exhibited,

differed from the Crampton furnace chiefly in this, that the fuel was converted into a gaseous condition, whereas in the Crampton furnace it was employed in the form of an impalpable powder. Which system would be the best for puddling he did not wish to say; after all, the difference in principle was not so very great. He was engaged with Mr. Lloyd in some experiments on a practical scale which were going on in regard to puddling Northamptonshire ore; and an analysis which had been made of the iron produced certainly showed that there was the means of eliminating or rather of avoiding the entrance of phosphorus and sulphur into iron almost entirely; ultimately he believed success would be attained in dealing with the ore direct. Whereas in puddling, a material had to be dealt with which had a great deal of impurity put into it in the blast furnace, he wished to avoid this impurity, and to prevent its entrance into the mass of metal. In other words, in the blast furnace nearly the whole of the phosphorus and a great deal of the sulphur entered into combination with the metal, because the reducing action in the blast furnace was very great; whereas in the ore-puddling furnace, as it might be called, the phosphorus, which was in an oxidised condition in the ore, remained in the oxidised condition, and could not enter into combination with the iron because it was never brought from the impure to the pure condition. Hence from an ore which contained 2·50 per cent. of phosphoric acid was obtained an iron containing 99·70 per cent. of metallic iron, 0·05 to 0·06 per cent. of silicon, and less than 0·10 per cent. of phosphorus. This and further analyses which had also been made would he thought show that even this small percentage of phosphorus, less than 1-10th per cent., was generally contained in the slag mixed with the iron in the ore-puddling furnace, and not in the iron itself. These questions had now been taken up in various ways, and he hoped to see a solution of the great problem of mechanical puddling arrived at. There was no doubt that if mechanical puddling were once accomplished in such a way as to avoid the inconveniences which had been met with hitherto, and which consisted chiefly in keeping the apparatus in good order, and in keeping good fettling or good lining in the furnace, a point would have been arrived at where the

ordinary puddling work, not fit for any human being, would be done away with. In the Crampton furnace an improvement had been made which got over the difficulty that had been encountered with the Danks furnace and other attempts, by introducing a water casing; that was no doubt a very good thing. In puddling ore there was rather less difficulty with regard to the fettling, because the charge remained solid until the very end of the operation and there was consequently less time of contact between the lining and fluid slag. Hitherto he had not resorted to similar means, but in the Crampton furnace no doubt it was a matter of great importance to have this water covering.

The percentage of the yield depended a great deal on the richness of the ore. From rich ore nearly the whole of the iron could be obtained, because the cinder remaining was consolidated and formed the bottom of the furnace; but in dealing with poor ore, such as Northamptonshire ore, so good a result could not be obtained; still, even from this ore, a yield of 75 to 80 per cent. of the whole quantity of metal in the ore had been obtained in the ore-puddling furnace.

Mr. CRAMPTON said that in the paper which had been read his intention had not been to enter into the practical working of the rotary furnace as regarded the fettling and the various qualities of iron that might be produced from it; he had assumed that was beyond question. So much had been done by Mr. Danks and others with regard to the action of revolving furnaces in producing good material, that he had not wished to lengthen the paper by dwelling upon a question which he and many others believed had been solved, particularly with regard to fettling. If it were true, as was unquestionably the case, that such bars as those now exhibited to the meeting were produced from Cleveland pig with 8 cwt. of fettling per ton of pig, it mattered little what was the cost of the fettling; no one would ever think of using inferior fettling when the best could be obtained. Taking the case of its being made from scrap iron which had to be bought, and supposing the fettling cost £2 per ton, experience showed that more than half the iron that

was in the fettling could be got back from it; and therefore, if the iron was worth £6 or £7 per ton, that would give a good profit. The fact that a lot of rubbish in the way of fettling could be got at a cheap rate in that and other ironmaking districts was no reason for it to be used. The result of using inferior fettling was that from 5 to 10 per cent. of the iron that ought to be obtained was lost; that was partly due to the fettling and a great deal to the bad manipulation; the value of the fettling was also lost. But what had been proved beyond question he thought was that first-rate fettling, which would cost £2 per ton, with mechanical puddling would produce 98 per cent. of such iron as the samples exhibited, from 100 of pig charged. At Woolwich experiments had been made in which as much as 104 per cent. of finished bar iron had been obtained from 100 of pig iron. He did not know what amount of fettling had been used in that case; no doubt there was more than 8 cwt. per ton. Supposing then that scrap iron had to be put in to make good fettling, under those circumstances it was good economy to use the very best that could be obtained.

He was very glad to find that Mr. Walker, the father of mechanical puddling, was present; very great service had been done in this matter by him and his friends, and he was very glad that they had made the move they did in starting it. It appeared that certain good results had been obtained by Mr. Walker, but cold-short iron had been produced; there was in fact too much of the brick lining in the iron.

With regard to Mr. Spencer's furnace, the second one made did not go to pieces quite so fast as the first; but there was no doubt that the second was still an impracticable one, mechanically at least, from his own point of view. There had been no mode of keeping it true in shape during working, and he had seen pinions of 3 in. pitch with the teeth broken, on account of the power required to drive it being so excessive, and so much out of truth. It cracked, and went to pieces; but there was no doubt it did remarkably good work while it lasted. Balls of 28 cwt. all in one piece had been made; they were broken up into three or four pieces or more, the iron produced being extremely good. Mr. Spencer had

also followed his predecessors in the question of the fettling, by putting it in melted.

The idea of using the best tap cinder for fettling had originated he believed with Mr. Edward Williams, as had been mentioned at the Paris Meeting of the Institution in 1867, and also with Mr. E. Riley, who had stated that the mill-tap cinder was the best material; and so it turned out to be. When liquid cinder bottoms were used, the liquid cinder tapped out was, when convenient, poured into the puddling furnace to repair it; the principle of using liquid fettling was not new, but it was a very good way of re-fettling a furnace after wear.

The question of analysis was one that he had not gone into in the paper, because he conceived that all such matters were practically settled already as regarded the product obtained from the rotary furnace; his view was that everything was now solved except the mechanical problem. All the excellent samples exhibited were absolutely useless, unless the machine which had produced them could go night and day, so as to realise the full results. In now bringing this furnace forward for the consideration of the Institution, he himself did not know how to improve it; taking the Woolwich furnace as it stood, he could not see what to do to improve it. He had asked the highest practical authorities who had seen the furnace, what alteration was required to make it a practical tool; and having received no suggestions and heard no complaints as to its mechanical structure, he concluded that no practical objection could be discovered to the furnace as it stood for use in common ironworks. It had now been worked for $2\frac{1}{2}$ years intermittently. It was frequently started from the cold furnace, and in three hours a 10 cwt. ball was turned out ready for the hammer. It only took three quarters of an hour to get the furnace to a white heat with 4 cwt. of coal; that was done every morning. The edge or lip of the revolving vessel, which was the great difficulty where high temperatures were employed in other revolving furnaces, had given no trouble in this, as it was self-fettled; and the body of the fluepiece, the carrying rollers, and the other wearing parts were as good now as they were when first put in, and the joint face continued

perfectly true and in good order. He came therefore to the conclusion that engineers and ironmasters had no objections to make with regard to the construction of the furnace as worked at Woolwich; some little deviations from the Woolwich plan that had been made in other furnaces had been thought to be improvements, but were really found not to be so. The cost of the furnace depended upon the size and upon a variety of circumstances; but it might be taken that, if new plant had to be put down, it would cost considerably less to turn out a given quantity of iron with the revolving system than with the ordinary hand puddling.

It had been intimated by Mr. Head, who was himself a plate maker, that plates could be made as good from a pile of pieces as from a single large bloom; and it was thought by him that with a single large bloom there were certain surface defects which he had pointed out, and which he (Mr. Crampton) had only seen very lately, that would interfere with the sale of the plates. But these surface defects had really no effect upon the value of the plate itself or upon its strength; it was he thought a mere question of proper rolling. The samples exhibited, which had not been made by himself, but in the ordinary course of work without reference to any consideration except that of making good material, showed the great superiority of the material produced by the rotary furnace over that produced by hand puddling. The specimens of plates exhibited, rolled from single blooms, were quite equal in quality to the best Yorkshire plates; some of the samples had been planed down to the interior, polished, and etched with acid, and on examination with a magnifying glass the iron was seen to be homogeneous and almost as pure as cast steel, whereas the best Yorkshire or other plates were full of cinder. It might be good to have cinder in the iron, but he did not think it was; important purchasers of plates had determined to have no laminated plates if they could get homogeneous ones.

In reference to the analyses given by Mr. Head, he might remark that the best cold-blast iron he had tried was from Sweden, and from India mentioned by Mr. Shanks; and he had also tried various irons in this country, both bad and good, and in no case did

the best cold-blast iron give better results than the Cleveland pig. There was no better steel made than the specimens exhibited produced from Cleveland pig containing 1·3 per cent. of phosphorus; and the sample of iron wire drawn out to No. 28 gauge was as good as any that was made; no better tin-plate could be produced than the sample exhibited, made from common Cleveland pig. In his own experience he had found no iron produced was better than that made in the rotary furnace from common Cleveland pig. Referring to Mr. Head's diagram showing the analysis of the iron in a puddling furnace, it was seen that the great mass of the material was pure iron, and all the impurities were contained in the little corner of the diagram. If a similar diagram were drawn out for Cleveland pig or any other pig, and were put side by side with the one exhibited, scarcely any difference would be perceived, and it would be impossible to tell by looking at them which was good or which was bad iron; the small percentage of inferior matter in excess in one over the other would hardly be perceptible. Therefore if that small corner of the diagram were eliminated, there remained the best iron, no matter what name it might go by. It must therefore not be considered surprising that bad pig could be made into good iron; it was a mere question of getting out the impurities.

The impurities were eliminated from the pig in this furnace better than in other puddling furnaces because there were two important elements gained by the system. There was—what all revolving furnaces had—a perfectly homogeneous action in eliminating impurities; and what was of equal importance, there was absolute power of regulating the quantity and quality of the flame. When it was considered that 10 cwt. balls, ready to be discharged, had been kept in the furnace for two hours exposed to the full heat without wasting the iron, it would be seen that there was complete power of regulating the flame so as not to produce oxidation. It was not possible for any of the dust coal or the dirt contained in it to enter the iron; the coal, should it touch the iron, was consumed, and the dirt melted into slag. Coal containing 20 per cent. of ash had no practical injurious effect on the iron; this had been watched with the utmost care.

He agreed with Mr. Carbutt in thinking well of steel; and he believed it would play the part of iron in a great many cases—indeed in nearly all cases, unless ironmakers made better material in general than at present. That was one of the reasons why he had brought this paper forward: he desired to show that with proper puddling it was possible to make in a cheap manner with a single large bloom articles equal to the best now produced. If this could be done, there was a future for iron where steel could not be made cheaper. But if steel—melted material—could be made cheaper, and could be welded and treated in all respects as wrought iron had been, then iron must give way to it.

As to the manipulation of these large blooms, there was not any difficulty about it. The specimens exhibited of pieces of plates had been made from 8 cwt. and 10 cwt. blooms, and he considered were equal to anything produced in Yorkshire. These had not been results obtained from isolated experiments; some of these blooms had been selected out of hundreds of tons, and had been rehammered and rolled off into plates; and the same was the case with the armour-plate bolts exhibited. There was no difficulty in cutting up these large blooms, if desired; there were appliances for cutting up a 10 cwt. bloom into a dozen pieces without any difficulty; but this new system of working 10 cwt. or 20 cwt. blooms could not be taken into small works with small plant. There must be hammers large and heavy enough to deal with such large masses, and the present system would have to be changed up to a certain point. If necessary, as had been mentioned, the ball could be cut into pieces in the furnace itself; of course large balls could not be manipulated with small machinery, but small furnaces could be constructed to puddle small charges to suit any works, though the economy in production would be less.

With regard to the cost and quality of the fettling, he considered it hardly mattered what the cost was, because, as already pointed out, even in the use of the most expensive fettling that could be employed there was a safe profit. With regard to the quality of the fettling, a pertinent remark had been made by Mr. Cowper; there was no doubt the first workers with revolving furnaces had the notion

to make fettling that would permanently stand; but the question was not quite understood at the time. That had unfortunately been the view taken in Mr. Menelaus' experiments; and he believed that, if during those experiments it had occurred to him that the lining must necessarily be repaired now and then, he would have solved the question, as he used materials suited for the purpose. It had been thought then that the fettling was to last permanently; but the matter had not been sufficiently investigated to find that it could be repaired without any inconvenience, as was now done.

With regard to the very good iron made at Mr. Heath's works by means of the Danks furnace, he had himself been there two or three times and had seen what was being done; and there was no doubt that the greatest attention had been given to the subject for a considerable time by the manager, Mr. Prior, in endeavouring to keep those furnaces going; but of course it was hopeless; no machinery could for a long period stand where it was subject to a white heat inside with nothing to protect it effectually on the outside.

The ductility of the material produced from the dust-fuel furnace was an important point. In many instances the product of the furnace had been a sort of puddled steel, having a tensile strength up to 28 tons per sq. in., the metal elongating 20 per cent. before it broke. But for common purposes his impression was that the plates ordinarily produced from the rotary furnace, having about 20 tons per sq. in. tensile strength, and stretching about 30 per cent., would be far superior in practical working, where they had to be punched, in comparison with plates that would stand 24 tons tension per sq. in. and only stretch 10 or 15 per cent. He had made a series of experiments with punched and riveted plates, using all the best classes of iron in the country, the best Yorkshire, and the homogeneous material from the rotary furnace; and in the best Yorkshire plates the deterioration caused by punching reduced the tensile strength from 22 tons per sq. in. to 16 tons; but under the same conditions the homogeneous plates with a tensile strength of $20\frac{1}{2}$ tons per sq. in. lost only $1\frac{1}{2}$ ton per sq. in. by punching, in consequence of their ductility. The value

of a plate under ordinary conditions did not depend upon its ultimate strength, but upon its strength when worked up in any structure. The ductility of the homogeneous metal was also shown by the extraordinary specimen of the armour-plate bolt broken by impact, which had stretched 50 per cent. before breaking and had been reduced 70 per cent. in area. His belief was that no such ductile iron had ever been previously manipulated.

The cost of drying the fuel for grinding was a secondary consideration, especially if there were ashes in the works which had to be used up. There was always plenty of waste heat from the rotary furnace, not only to give steam and heat the air, but also to dry the coal, which was brought in trucks and need not be touched by hand any more.

With reference to the American experience in regard to dust-fuel, he had tried not only American anthracite, but charcoal and almost every kind of fuel, and had very recently been using coal with 20 per cent. of dirt in it, with which he had obtained excellent heats. As to anything like dirt or unconsumed material, there was not a particle remaining from the rotary furnace; the fuel all went into perfect combustion. The combustion took place close to the bloom in the furnace. There had been he supposed 2000 tons of coal through the Woolwich furnace, and no inconvenience whatever had been experienced in the shape of oxidation or from unconsumed dust accumulating. Sufficient temperature could be obtained with dust-fuel to melt wrought iron, as shown by the specimen exhibited of wrought-iron shavings which had been fused together in an hour; that would require the combustion of the coal to be nearly perfect and regular to accomplish this.

With respect to the Indian iron sent over by Mr. Shanks, there appeared to be no difference between that pure iron and others, as regarded the product obtained from the rotary furnace. The direct process carried out in Mr. Siemens' ore-puddling furnace was he thought in the right direction; and he understood from Mr. Shanks that in some districts in India malleable iron was being made direct from the ore by putting charcoal with rich ore into one of the small native smelting furnaces, and the bloom obtained from it was then

heated to a high temperature in a charcoal furnace, and then hammered out, producing a remarkably pure and clear iron. That was he supposed the process now carried out in making iron in India; and if necessary it could be done in the rotary dust-fuel furnace.

The PRESIDENT desired to draw attention to one or two points, if not for their immediate bearing upon the paper now under consideration, yet for their relation to matters connected with this great and important subject. For somewhat more than forty years the attention of manufacturers of iron had been directed rather to the production of large quantities than to the production of iron of excellent quality. The consequence had been that the users of that iron had not been able to depend, with that precision which was necessary for constructive purposes, on the strength of the material which they had had to employ. It might be that nine pieces out of ten used in an important structure might come up to the strength which the engineer had calculated upon, but then the tenth might altogether fail; and as the strength of a structure was only that of its weakest part, the result was that a failure took place or some disaster, or disappointment of a serious character ensued. The effect had ultimately been not merely to occasion distrust at home, but what was still worse to occasion distrust abroad; and no one could help seeing that other nations, who probably would never have thought of entering into competition with this country, had been driven to manufacture their own materials, as he knew by experience in a number of continental and other countries to be actually the case, because, as they said, they could not depend upon the quality of the iron received from England. He thought it was of national importance that distrust should be removed; and he was very glad to find that Mr. Crampton and Mr. Siemens and many other gentlemen were now directing their attention to this subject and working in the direction of improvement. This country possessed enormous mineral resources of various kinds, and it happened with regard to the iron trade, that usually, though not invariably,

coal and ironstone were to be found almost in proximity to each other; but unfortunately the ironstone was not always of the most suitable quality, and in one case which had been very much alluded to in the course of this discussion the ironstone contained a remarkable amount of a most important impurity, namely phosphorus, in the state no doubt of phosphoric acid. As a plain illustration of that condition of the ore, which afterwards became the condition of the iron, he would mention that a ton of iron was about 5 cub. ft., or a cube with sides of rather more than 20 in. length. As it was the general custom to view the chemical composition of solid substances by percentages of weight and not by bulk, it might be a matter of surprise to find that whilst a ton of iron only occupied a cube of 20 in., the quantity of phosphorus contained in that iron, supposing it to amount to 1·3 per cent. by weight, occupied a cube of nearly 8 in., or a sphere of 10 in. diameter; to many ironmakers that fact had perhaps not presented itself in that particular form. Now the quantity of phosphorus which remained in the iron as it came from the blast-furnace exercised a most important influence; it gave that peculiar quality to wrought iron which was called cold-short. But it did more than that; turning for a moment to the question of pig iron, the phosphorus in pig cast into water pipes was occasionally found in the water which passed through those pipes. If it happened to be peculiarly soft water, or water which contained organic matter and which remained stagnant in the dead ends of those pipes, the water became most offensive, and gave rise to great complaints in the case of water companies who happened to have that particular character of water to deliver, and whose pipes were cast from that particular character of iron. It was therefore of the utmost importance, both as regarded cast iron for many purposes and also as regarded wrought iron for all purposes, that the phosphorus should be removed. But then there was another evil of this phosphorus, namely that according to the present method of manufacturing steel by the Bessemer process the phosphorus was not removed; it remained in the so-called steel, and it

prevented the iron from assuming the character of that kind of steel which ought to be attained, namely a cheap steel of reliable quality by the first process of conversion. What Mr. Crampton had done would he believed lead to many most important considerations and to valuable results in respect to the removal of phosphorus; and perhaps to the future ability to make Bessemer steel from a material from which it could not now be manufactured. He believed that the effect was to a great extent a chemical one; that was a point that he thought had not yet been adverted to. Both by the Siemens and by the Crampton furnace the fuel was converted into a hydro-carbon gas, and, as it appeared to him, that gas was further decomposed in the process, the carbon assuming probably the form—certainly ultimately—of carbonic acid gas, and the hydrogen taking up the phosphorus in the form of phosphoreted hydrogen, thereby leaving the metal pure. Now it had occurred to him that, if that were so, probably the purification of the iron might take place in the Bessemer converter by blowing the hydro-carbon gas through the metal in its melted state, at all events for a time, but whether in the first instance or secondly would be matter for determination by trial; for if, as he believed, it did form phosphoreted hydrogen, then that pernicious ingredient phosphorus would by that process be removed. The so-called water-gas consisting chiefly of hydrogen might also be tried with some probability of success.

But with regard to these two gas-producers, the Siemens and the Crampton, it certainly did appear to him—leaving out of view the rolling apparatus for the production of the bloom, and considering only the production of the gas—that the Siemens apparatus would produce the purer flame; because in the other case the raw coal itself with all the impurities which were contained in it was blown into the furnace, while by the Siemens process nothing was carried in but the pure gaseous materials themselves. On that ground he thought it would ultimately be found that for the production of a very pure material the Siemens gas furnace would probably turn out to be preferable to the Crampton dust-fuel furnace. He thought it desirable that some experiments should be made in the direction thus indicated; and he hoped the results would be communicated to the Institution at a future meeting.

He proposed a vote of thanks to Mr. Crampton, which was passed, for his paper and for the extensive and interesting series of specimens he had exhibited.

A portion of the above discussion took place on Wednesday, 19th July.

The Adjourned Meeting was held in the Midland Institute lecture theatre, Birmingham, on Wednesday, 19th July, 1876; THOMAS HAWKSLEY, Esq., President, in the Chair.

The following paper was read:—

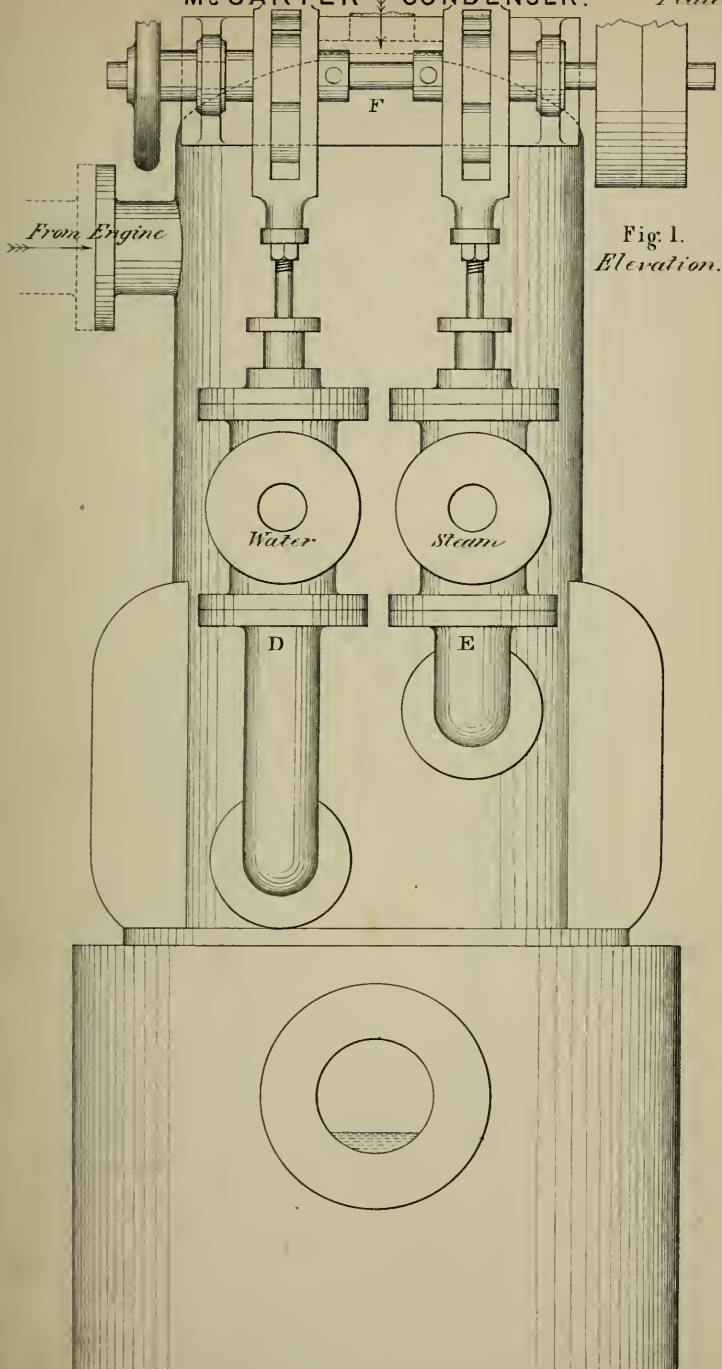


Fig. 1.
Elevation.

(*Proceedings Inst. M.E. 1876*) *Scale* 1/10th 0 5 10 15 20 *Ins.*

Mc CARTER CONDENSER.

Plate 48.

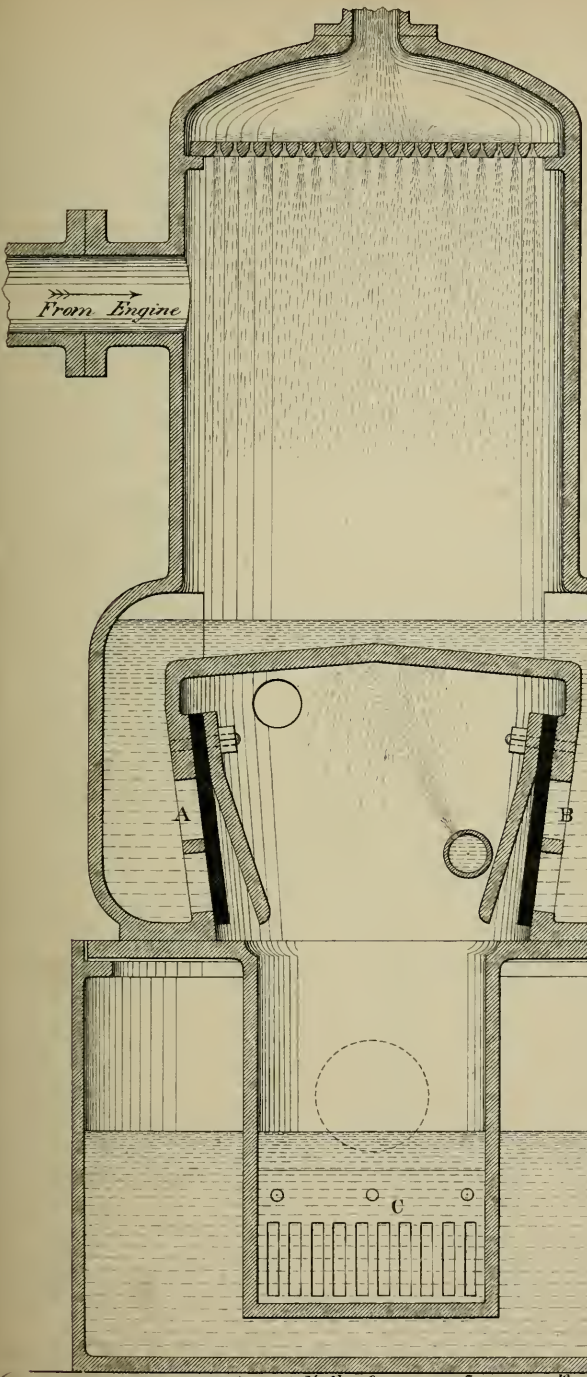


Fig. 2.
Vertical Section.

(Proceedings Inst. M.E. 1876.) *Scale 1/10th.* 0 5 10 15 20 Ins.

Mc CARTER CONDENSER.

Plate 49.

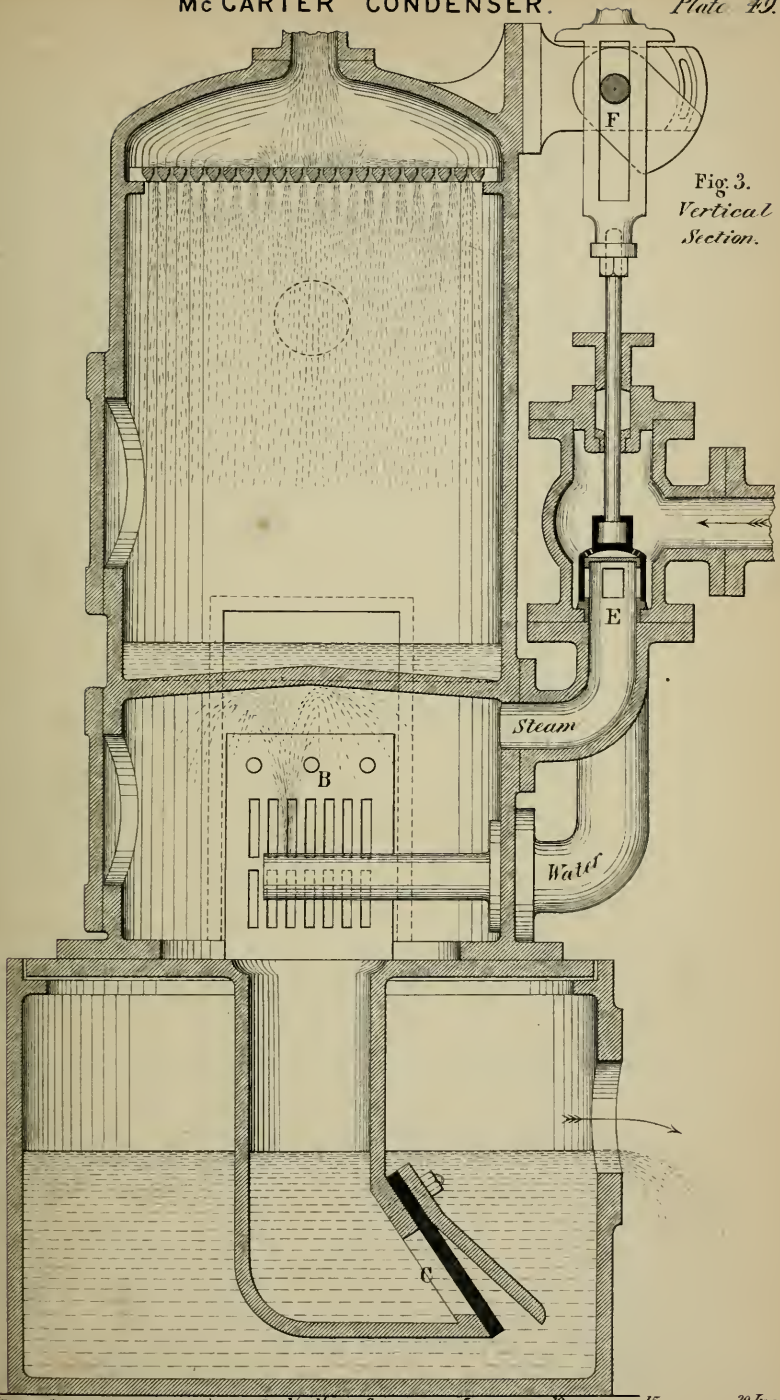


Fig. 3.
Vertical Section.

(*Proceedings Inst. M.E. 1876.*) *Scale 1/10th* 0 5 10 15 20 Ins.

FRISBIE MECHANICAL FIRE-FEEDER.

Plate 50.

Fig. 1. *Longitudinal Section.*

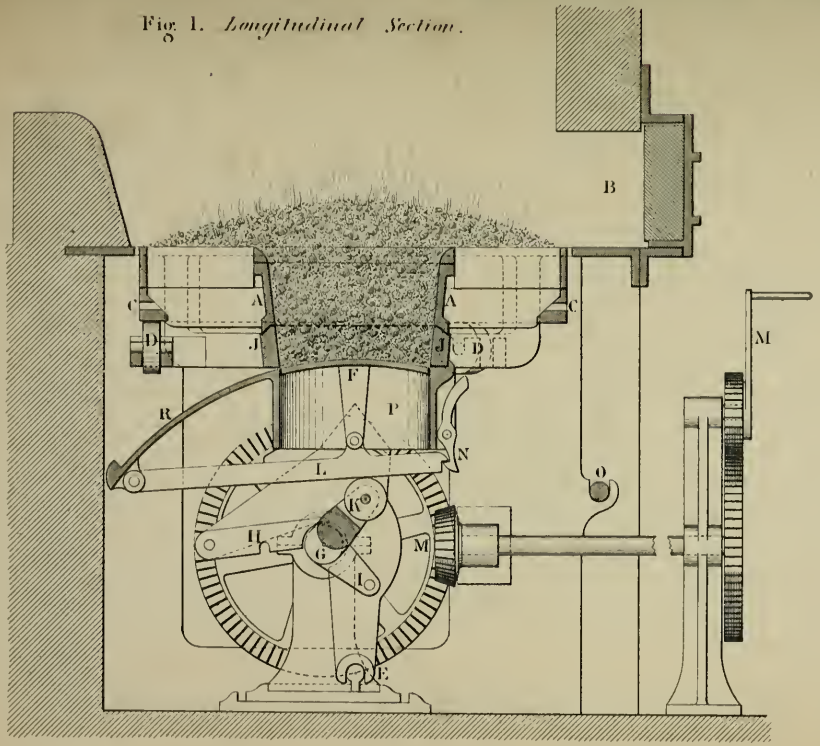
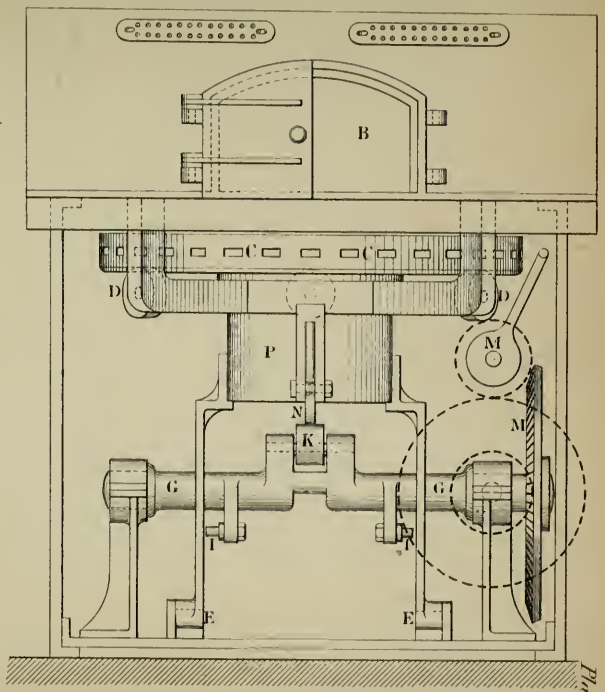


Fig. 2. *Front Elevation.*



(Proceedings Inst. M.E. 1876.)

Scale 1/20 th

Ins. 12 6 0 1 2 3 4 5 Feet.

Plate 50.

Fig. 3. *Longitudinal Section.*

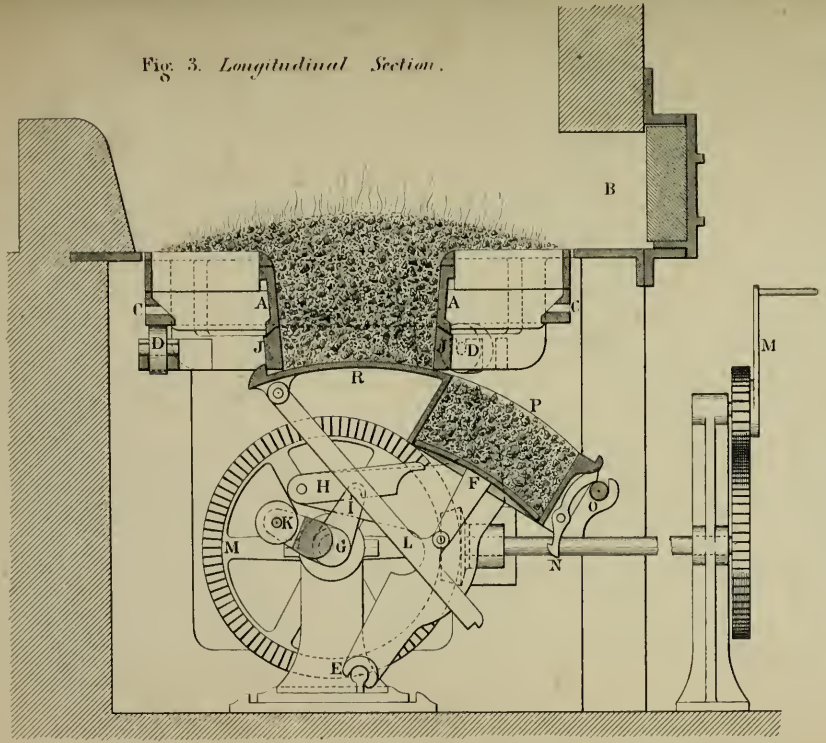
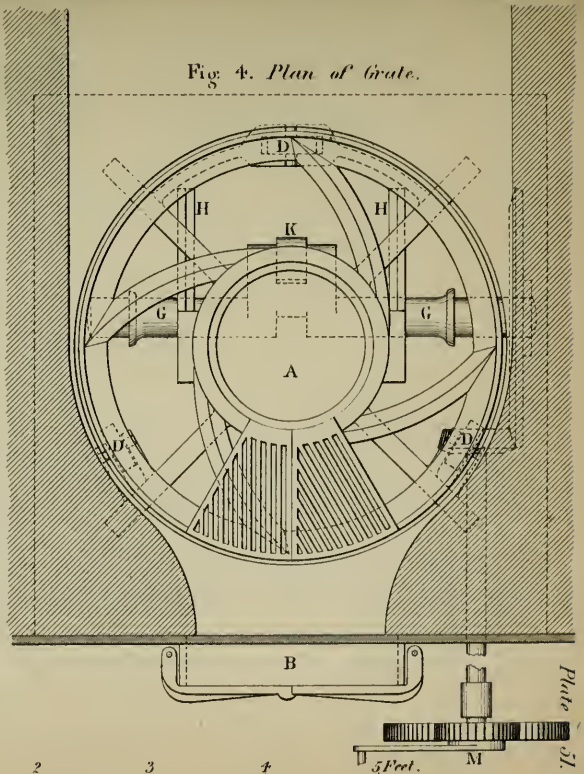


Fig. 4. *Plan of Grate.*



(*Proceedings Inst. M.E. 1876.*) Scale 1/20th Ins. 12 6 0 1 2 3 4

Plate 51.

FRISBIE MECHANICAL FIRE-FEEDER.

Fig. 5.

Cylindrical Boiler.

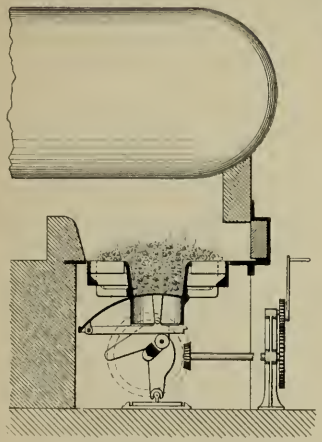
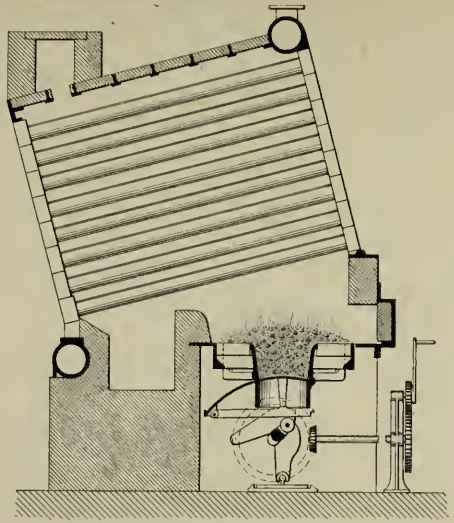


Fig. 6.

Multitubular Boiler.



Scale 1/60th

0 5 10 Feet.

(Proceedings Inst. M.E. 1876.)

Fig. 7. *Glass Furnace.*

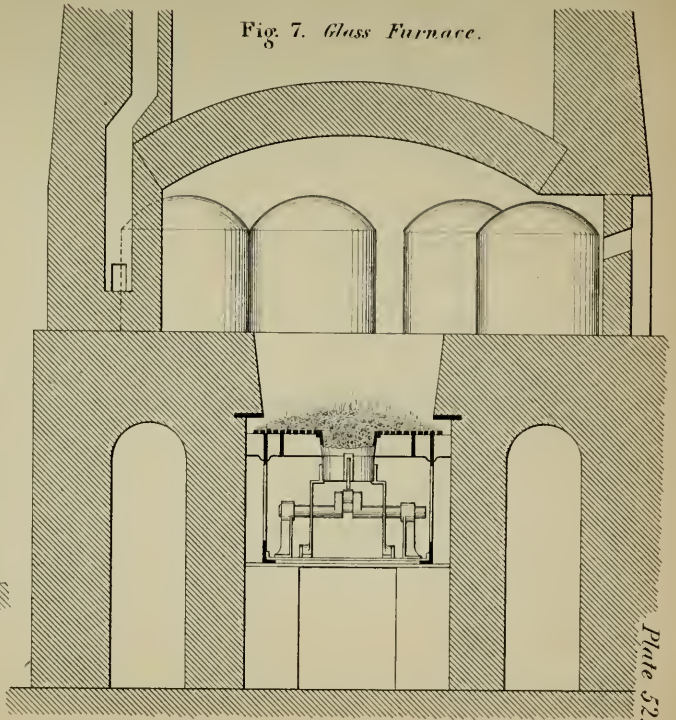


Plate 52.

ON THE Mc CARTER CONDENSER WITHOUT AIR-PUMP FOR STEAM ENGINES.

By Mr. FRANCIS PRESTON, of Huddersfield.

The Air-Pump and Condenser combined, in 1765, by either James Watt or Gainsborough, and successfully introduced by James Watt, have undergone very little modification since they first left his workshop. The few alterations that have been introduced have in no essential altered the principle or general arrangement. Many attempts, with varied success, have been made to introduce a condenser without an air pump. The writer believes there has been no successful application of a condenser without the aid of an air pump, and capable of lifting its own injection water, previous to the one now forming the subject of this paper.

The late John McCarter, of Londonderry, was the inventor of the condenser that forms the special subject of the present paper, and he made further improvements in subsequent years for perfecting his original invention. Unfortunately he has not lived to reap the merited reward of his beautiful and simple invention, having died last year just at the time when his invention was beginning to be practically appreciated. McCarter's invention takes as a basis the ordinary condenser and adheres pretty much to the present recognised proportion, admitting the exhaust steam and the injection water in the usual way. To dispense with the air pump is the object he had in view, and to substitute a simpler and less costly mode of discharging the water and air that continually accumulates in the condenser when at work, and at the same time to be enabled to place the condenser in any position and elevation with respect to the cylinder that is found most convenient. This condenser draws its own injection water from any depth as in the ordinary condenser,

and, being enabled to work at any elevation, it can be so placed as to allow the waste water to flow back again to any desired level. The condenser is provided with a small auxiliary condenser placed at the bottom of the ordinary or condenser proper, and worked separately and independently, being connected with the ordinary condenser by two intermediate india-rubber foot valves. These valves are worked by means of forming a vacuum in the auxiliary condenser by introducing a separate jet of steam and water, supplied alternately by independent mechanical means, thereby alternately creating and destroying a vacuum, about five times per minute. The act of making this vacuum enables the intermediate valves to open, forming a connection with the condenser proper, thereby allowing the accumulated water to flow into the auxiliary condenser; and destroying the vacuum by a jet of steam admitted into the auxiliary condenser causes the intermediate valves to close, and at the same moment opens the delivery valve in the hot-well, thereby discharging the hot water and air, which flow away in the ordinary manner.

The construction is shown in Figs. 1 to 3, Plates 47 to 49. Fig. 1 is an elevation of the condenser, with the small auxiliary condenser and hot-well complete, and ready for the connections. Fig. 2 is a vertical section, showing the two foot-valves A and B which connect the condenser proper and the auxiliary condenser; C is the discharge or delivery valve. Fig. 3 is a vertical section at right angles to Fig. 2, showing the independent water and steam valves D and E in connection with the auxiliary condenser. F is the tappet shaft, giving motion to the two equilibrium valves D and E. This shaft revolves about five times per minute, and is worked either direct from the engine or from any other convenient shaft. The water valve D is connected with a supply of water at a higher elevation than the auxiliary condenser; and the equilibrium steam valve E is in connection with the boiler, from which it receives a supply of steam five times per minute. This jet of steam is diminished in pressure by a diminishing valve placed near the boiler, so as to give the jet of steam at an average of 3 lbs. to 4 lbs. pressure above atmosphere

when entering the auxiliary condenser. The McCarter condenser draws its own injection water in the same way as an ordinary condenser, and there are some at work successfully lifting their own water 22 ft. to 24 ft. vertically.

These condensers have now been successfully at work upwards of three years in conjunction with engines from 12 in. cylinders to 37 in. cylinders, and they are giving great satisfaction, effecting a considerable saving in coal, besides giving much steadier motion to the machinery, caused by the regularity of the working of the condenser, without the great strain being put upon the engine through the ordinary air pump at every revolution of the engine. The power required to work the tappet shaft is hardly worth a consideration; and this shaft can either be worked direct from any convenient part of the engine, or may be worked from any counter-shaft or other independent motive power.

As an illustration of the successful application of these condensers the writer would mention the first condenser introduced in Yorkshire, which was applied to a compound horizontal engine, with a condensing cylinder 20 in. diameter. This application was introduced in order to make the power previously absorbed in working the air pump available for driving the engines 3 strokes per minute faster, with the same machinery thereon, and without any especial reference to economy. The result was stated by the proprietors of the mill to be that the engines have done more work in the mill than in any other month, with a regular speed and with greater ease, besides saving fuel in money value amounting to 33 per cent.

Another case to which the writer wishes to make reference is one of these condensers recently fixed at the Travis Brook Mills, Stockport, which case illustrates the great utility of this condenser in all modern engines of quick speeds. This engine was also a compound engine of recent build, having a condensing cylinder $31\frac{1}{2}$ in. diameter, to which was first applied a double-acting vertical air pump; and afterwards, when the effect upon the engine at the completion of its stroke was thought to endanger the safety of the

engine, a single-acting air pump was substituted, the effect of which was found to be still worse than the double-acting pump first applied. About six weeks ago a McCarter condenser was attached to these engines in lieu of the air pumps, and the improvement in the working of the engines is stated to be very great, every appearance of uneasiness previously experienced by the loud report at each descent of the piston having wholly disappeared, also giving steadier driving to the machinery. This proves what in the writer's opinion will be found in future quite practicable, namely that with this condenser condensing engines may be worked at the highest speeds at which non-condensing engines now work or may hereafter be made to work, thus securing the additional advantage of a vacuum to that of the highest speeds without the slightest difficulty; and if so, it must always give to the condensing engine the advantage over non-condensing engines in obtaining the greatest amount of duty with the smallest size of cylinder, with a given pressure of steam, besides the advantage in point of economy due to a condensing as compared with a non-condensing engine. This advantage is obtained without any perceptible increase of friction, or of complication in the construction of the engine.

In reference to this part of the subject, attention is drawn to the great resistance of an air pump, causing the difficulty engineers frequently experience in balancing engines, so as to avoid the irregularity of motion due to the air pump, a difficulty admitted generally to be so great in the single-crank horizontal engine as to render it almost impossible to avoid its effect being plainly indicated at each revolution of the engine upon the slide of the governor. Take for example a 22 in. single-action air pump, working at half the stroke of the engine, which is about the usual proportion for a 34 in. cylinder engine nominally of 40 H. P.: then with an ordinary vacuum of $12\frac{1}{2}$ lbs. in the condenser there would be, at the moment of discharging the hot water, over 2 tons of atmospheric resistance, in addition to the weight of water lifted at each half stroke of the engine and the friction of the pump with its members. And then it is to be remembered that this resistance does not take place at each stroke, but at every alternate stroke, and at only one part

of such alternate stroke, and that part being towards the termination of the stroke, consequently at a time when generally there is not sufficient steam in the cylinder to overcome the friction alone of the engine, in addition to the great resistance of atmospheric pressure upon the air pump; with these conditions the difficulty of effecting a uniform motion in the engine is not surprising.

Another application of this condenser is one recently made to a new engine by the Catterall Paper Company, Catterall, near Preston, who, requiring the water to be at a higher level than the level at which their supply is obtained for manufacturing purposes, have fixed the condenser above the engine for the purpose of drawing the water from the low level and delivering the same at a much higher level, thus answering the two purposes combined, namely that of a condenser and also that of a lifting pump, by which means the water will be raised to the required level without any expenditure whatever of either power or fuel. It may also be added that this condenser is well adapted where one condenser is required for a number of small engines to exhaust into, such as are used in driving calico printing machines, where there may be several small engines in one room. For this purpose a McCarter condenser is now being applied to Messrs. Dewhurst's Aspley Print Works, where six small high-pressure engines are being made to condense into one condenser.

For Colliery Winding Engines the writer believes this condenser will be of the greatest advantage, enabling them to work upon the condensing instead of the non-condensing principle, as at present in general use. The principal reason why winding engines are not made condensing engines is that with the air pump the engine would not form its vacuum until after the engine had been set to work for some short time, and meanwhile would require to work non-condensing. With the McCarter condenser this is obviated by working the two tappet valves constantly by means of a small donkey engine. By this arrangement a vacuum in the condenser would be constantly maintained when the winding engines were stopped, and consequently there would be at all times a vacuum ready for exhausting into, the moment the winding commenced. The executors of J. Hargreave, of Burnley, are now applying this

plan of condensing to a pair of 28 in. cylinder winding engines at Bank Hall Colliery, the firm having already had experience in the working of the McCarter condenser for large pumping engines at several of their collieries, where they are giving most satisfactory results. The introduction of a separate motive power for working the condenser, so as always to have a vacuum ready for the starting of the engines, is due to Mr. Waddington, the manager of the extensive collieries belonging to the above-named firm, who has successfully applied a small donkey engine with 3 in. cylinder to work the tappet shaft of the condenser recently applied to a pair of 25 in. cylinder pumping engines, and he is now also applying the same principle to a McCarter condenser which is being made for a pair of their 28 in. cylinder winding engines.

The following are the particulars of a recent calculation made by Mr. James Wood, Engineer, of Burnley, in which a comparison is made as to the relative volumes of steam expended in the working of an ordinary air pump and the McCarter condenser, in an engine at Messrs. Crossley and Sons' Albion Mills, Halifax, diagrams from which were taken in July, last year. The engine is a horizontal compound; high-pressure cylinder, $14\frac{3}{4}$ in. diam., stroke 4 ft.; low-pressure cylinder, 34 in. diam., stroke 4 ft.; rev. 65 per min.; Ind. H. P. 216. The boiler supplying the engine is multitubular, having a total heating surface of 840 sq. ft., and firegrate area of 36 sq. ft.

The following results supplying the data for the calculation were obtained from a nine hours' trial :—

Mean Pressure in Boiler, 67 lb.
Mean Vacuum in Engine, 13 lb.
Mean Temperature of Injection Water, 78°.
Mean Temperature of Water from Condenser, 104°.
Water discharged per min. from Condenser over tumbling bay, being a mean of 35 observations } 2215·94 lb.
Temperature of Feed Water, 200°.
Water Evaporated per lb. of Coal, 9·012 lb.
Water Evaporated per min., 68 lb.
Coal Consumed per Ind. H. P. per hour, 2·09 lb.
Do. Quality, Oaks nut slack.

In the absence of actual measurement, it is assumed that the vertical single-acting air pump, working at half stroke of the

cylinder, namely 2 ft., is 22 in. diam., which is a common proportion; and that the power absorbed by the air pump is equivalent to the sum of

1st—The Friction.

2nd—The Atmospheric Resistance.

3rd—The Weight of Water lifted.

Firstly.—For calculating the friction, it is assumed to be about the same as though the pump was lifting water to the extent of the capacity due to the whole stroke, as the bucket passes through the whole stroke when working; and the modulus is assumed to be the same as that of an ordinary lifting pump, namely 2-3rds, or 0·66 as the ratio of the work done to the H. P. consumed. Then 380 sq. in. (area of bucket) × 12½ lb. (net atmospheric resistance) × 65 rev. × 2 ft. stroke ÷ 33000 = 18·7 H. P. due to atmospheric resistance. And, 380 sq. in. area × 24 in. stroke × 65 strokes × 2 ft. (being a mean of half a 2 ft. stroke + 1 ft. constant head above the top level of bucket) ÷ (27·5 cub. in. per lb. of water × 33000) = 1·3 H. P. due to water lifted. Then 18·7 H. P. + 1·3 H. P. = 20·0 H. P.; and 20·0 ÷ 0·66 = 30·0 H. P. consumed, the difference of 20 from 30 being friction, = 10·0 Ind. H. P. due to friction.

Secondly.—In calculating the atmospheric resistance, taking the vacuum to be 12½ lb. instead of 13 lb. (which is more general perhaps), the resistance would be 12½ lb. per sq. in. of bucket area during the total lift of a column of 13 ft. of water per min. Thus, 2215 lb. total weight of water lifted per min. × 27·5 cub. in. per lb. of water ÷ (65 rev. of engine or strokes of pump × 380 sq. in. area of bucket) = 2·42 in. depth of water on bucket lifted at each stroke. Therefore 2·42 in. × 65 strokes = 157·3 in. or 13 ft. 1 in. column lifted per min., as stated. Then 380 sq. in. area of bucket × 12½ lb. per sq. in. net resistance × 13·1 ft. column lifted per min. ÷ 33000 = 1·88 Ind. H. P. due to atmospheric resistance.

Thirdly.—The weight of water lifted = 2215 lb. per min.; and assuming the height from the bottom of air pump to the overflow in hot-well to be 3 ft., (due to a 2 ft. stroke of pump + 1 ft. constant

head), then 2215 lb. × 3 ft. ÷ 33000 = 0·20 Ind. H. P. due to lifting the water.

Therefore	10·00	H. P. Friction.
	1·88	,, Atmospheric Resistance.
	0·20	,, Weight of Water lifted.
Total	12·08	H. P. absorbed in working the air pump.

Now 216 Ind. H. P., of which this 12 H. P. for working the air pump forms a part, was found to consume 68 lb. of water, evaporated at 67 lb. pressure; therefore 12 H. P. would consume 3·78 lb. of water evaporated at 67 lb. pressure. Steam at 67 lb. pressure + 15 lb. = 82 lb. total pressure contains a total heat of 1209·7°, which × 3·78 lb. = 4572 lb.-deg. or units of heat, and this according to the above calculation is the amount consumed in working the air pump.

The expenditure of steam in working the McCarter condenser is that consumed in the lower chamber or auxiliary condenser, which requires to be of sufficient size to contain the amount of water and air discharged at each revolution of the tappet shaft. In the present case the amount of water passing through the condenser would be the same as with the air pump, less the proportion due to the reduced load of 12 H. P. from having no air pump to drive. Also, there would be the water passing through the tappet valve, together with any air entering the condenser previous to each discharge, which this chamber would require to hold. The total water passing through the condenser with the air pump to work, the engine exerting 216 Ind. H. P., was found to be 2215·9 lb. per min.; and according to this proportion there would be 123 lb. per min. less water passing through if the 12 H. P. absorbed by the air pump were taken off, leaving 2092·9 lb. per min. as the actual amount of water passing through the upper condenser into the lower chamber; adding to this 35 lb. per min. for the water entering through the tappet valve, the total is 2092·9 + 35 = 2128 lb. per min., being 88 lb., or 2420 cub. in. less per min. than with the air pump. This difference of 2420 cub. in. being allowed as the space for the accumulation of whatever air there may be, then 2215·9 lb. × 27·5 ÷ 5 times per min. = 12187 cub. in. for the size of the lower chamber.

The pressure of steam admitted into this chamber is 3 lb. per in. above atmospheric pressure, and the chamber is charged with this pressure 5 times per min. This steam at 3 lb. above atmospheric pressure, or 18 lb. per in. total pressure, possesses a total heat of 1181·8° and a vol. of 1410 that of water. Therefore 2215·9 lb. of water per min. × 1181·8° total heat ÷ 1410 vol. = 1855 units of heat per minute in the steam with which the lower chamber is charged after discharging the water.

As regards the steam expended in expelling the water against atmospheric resistance—namely 2215·9 lb. × 27·5 = 60937 cub. in. of water per min., against 15 lb. per in. pressure—assuming that 60937 cub. in. of steam at 15 lb. total pressure has been required to perform this work, there is 60937 cub. in. of steam ÷ 1669 vol. of steam at 15 lb. ÷ 27·5 cub. in. per lb. of water × 1178·9° total heat in steam at 15 lb. = 1565 units of heat consumed per min. in expelling the water.

Now, 1855 + 1565 = 3420 total units of heat consumed per min. in working the McCarter condenser; or 4572 − 3420 = a difference of 1152 units of heat in favour of the condenser, or 25 per cent.

This comparison of 25 per cent. in favour of the McCarter condenser must not be considered as showing the whole economical advantage there exists over the ordinary air pump; and it must be borne in mind that in the foregoing calculation the comparison has been made with an engine whose expenditure of heat per Ind. H. P. is represented by almost the lowest consumption of coal per horse obtainable at the present day, namely 2 lb. per Ind. H. P. per hour; and that if the comparison had been with an engine having a consumption of 4 lb. of coal per Ind. H. P. per hour, (which is perhaps more nearly an average consumption), the difference would have been much more striking. It ought also to be borne in mind, in the absence of possessing a modulus of the friction actually due to an air pump working from 2 to 3 times the speed of an ordinary lifting pump, the modulus employed in the calculation has been that of the latter, and consequently the friction assumed must necessarily be much below what is actually due to the excessive speed of an air pump. This is also testified by some firms who have taken out

air pumps and substituted for them the McCarter condensers that were proportioned to the load upon the engine. It is only right to remark that, in cases where makers have fixed condensers with the lower chamber more than twice the proper size, the consumption of coal as compared with the air pump has been somewhat disappointing, but this excess is obviated when correct proportions of the auxiliary condenser and condenser proper are maintained; this need not therefore be any matter for surprise.

It should be pointed out that in all cases where this condenser is placed above the level of the engine cylinder, a small air valve is fixed inside the condenser, and works precisely the same as a ball tap, so that it is impossible under any circumstances for water to rise inside the condenser beyond a certain level, inasmuch as the water then lifts the valve, and, admitting the air, destroys the vacuum.

Mr. PRESTON observed respecting the calculations given in the latter part of the paper that he was not the author of them; and he had only taken an interest in the subject in regard to the practical introduction of these condensers. He believed one of their greatest uses would be for winding and pumping engines at collieries. Where they had been attached to the pumping engines the result had been so satisfactory that he believed for winding engines they would be found still more valuable. The condenser shown in the drawings was the full size suitable for a 12 in. to 15 in. cylinder; in the first instance the auxiliary condenser had been made larger than was necessary, and Mr. McCarter had not lived to correct that error. The condenser proper was not different from the condenser in universal use; the auxiliary condenser was simply to get rid of the water as it accumulated in the condenser proper. To obviate this, the tappet shaft revolving about five times per minute opened and closed alternately the steam and water valves

of the auxiliary condenser, thereby forming a vacuum in it equal to the vacuum in the condenser proper. The vacuum in the upper vessel had however an advantage over that in the lower by the weight of water that had accumulated above the two intermediate foot-valves; that excess of pressure opened the two valves, and the water in the upper vessel immediately flowed into the lower condenser, in which it was retained by the bottom foot-valve. The next jet of steam admitted into the lower vessel destroyed the vacuum in it, causing the two intermediate valves to close immediately, and the condenser proper was thereby isolated again from the auxiliary condenser. At the same time the bottom foot-valve, opening to the hot well, was opened by the weight of the water in the lower vessel; and there being no vacuum at that moment, the water flowed into the hot well and escaped at the overflow.

The condenser proper and the auxiliary condenser were cast in one piece, and the hot well was a separate piece, upon which the condenser rested without any air-tight joint; it was found better to have a little opening at the joint all round, as shown in the drawing, so that the air discharged along with the water into the hot well could get away easily without any obstruction.

The consumption of water was less than with the ordinary air-pump condenser; but that was not caused by any novel action, but by the amount of power taken from the engine to work an air-pump. Supposing the working of the air-pump took 5 or 10 per cent. of the power of the engine, there was so much less injection water required for the condenser proper when the air-pump was dispensed with. Against that, there was the jet of water required for the auxiliary condenser. The condenser proper would lift its own supply of injection water, the same as any other condenser; with an ordinary condenser it was preferred to lift the water 6 ft. rather than 24 ft., and the McCarter condenser lifted its own water neither more nor less than the ordinary condenser. The water for the auxiliary condenser required a head of say 1 ft.; the amount of head did not signify, as long as it was above the tappet valve; the valve being opened five times a minute, the head of water was wanted for closing it instantly the vacuum was formed.

The steam admitted into the auxiliary condenser to destroy the vacuum was supplied from any independent source, and it was found practically that from 4 lb. to 5 lb. per sq. in. pressure above the atmosphere was sufficient. Whatever was the working pressure in the boiler, the steam was taken off through a reducing valve, being only required for destroying the vacuum. In lieu of the expense of working the ordinary air-pump there was the expense of the steam required to destroy the vacuum in the auxiliary condenser, this being taken direct from the boiler.

The PRESIDENT enquired how the amount of steam was regulated, so as to avoid letting in too much and wasting it.

Mr. PRESTON said the object was to admit as little steam as possible. A series of sizes of auxiliary condensers suitable for different sizes of condensers had been originally given by Mr. McCarter, but he believed a mistake had been made by him in giving these too large, therefore taking more steam than was actually requisite to create and destroy the vacuum; because it was only required to make a vacuum just sufficient to relieve the two intermediate foot-valves. According to the original plan of Mr. McCarter these two valves were opened by mechanical arrangements, which were found not to answer well; they were now opened by simply destroying the vacuum in the auxiliary condenser, as before explained.

Mr. C. COCHRANE understood that the ordinary condensers would require about twelve times the weight of condensing water compared with the weight of the steam condensed. It seemed to him that the lower chamber of the condenser now described must require in addition a quantity of steam corresponding to a cubic inch of water for every cubic foot of water displaced. If twelve times the weight of the steam was required for condensing in the usual way, then there would be required more than twelve times the quantity of condensing water in this form of condenser, the steam necessary for displacement of the water needing to be supplied from the boiler; therefore all that was saved in the moving power would

be the friction of the engine in using that steam. Whether this were exactly a correct view or not, it occurred to him that there was more water to move in this condenser than in the ordinary condenser.

The PRESIDENT observed that there was the avoidance of shock in the condenser now described.

Mr. L. OLRICK had no doubt if the condenser was as good as it was represented to be there would be a great many opportunities of applying it; employers of steam power would be glad to avail themselves of the use of such a condenser. The use of the condenser for winding engines had been referred to, but he did not see why it should be particularly recommended for that purpose. It had been stated that the principal reason why winding engines were generally worked high-pressure and not condensing was that the air-pump of an ordinary condensing engine would not form the vacuum until after the engine had been set to work for a short time, and in the meanwhile the engine would require to work non-condensing. He did not think however that this could be maintained, because the same would apply to marine engines, and he knew from his own experience that what was done in that case was simply to blow the water out of the condenser by a jet of steam, and then open the injection cock and form the vacuum. The engine thus started at once with a vacuum, and he did not see why a similar plan could not be worked with an ordinary land condensing engine. As the calculation given in the paper was principally relied upon for proving that this condenser was superior to the ordinary air-pump, he thought this was an instance of how desirable it was that such calculations should be received in time to admit of their examination by the members previously, so that they might be discussed fully at the meeting; otherwise they were rendered practically useless for the discussion.

Mr. C. W. SIEMENS enquired about the amount of steam in the jet necessary to work the auxiliary condenser. A calculation had been

given of the quantity of water which this condenser required as compared with the ordinary condenser, and he supposed there would not be any material difference in the quantity, but he had considerable doubt as to the economy of working this plan. This condenser worked upon the Newcomen principle, boiler steam being admitted in the lower part of the condenser, which stood in lieu of a cylinder in the Newcomen engine; and the hot steam was brought into contact with the cold surface, in order to expel the water and air accumulated there. Now the quantity of steam so employed must be considerably more than the steam that would be necessary to work the air-pump, because the air-pump was worked on as economical a principle as was involved in the engine itself. Therefore the expulsion of a certain amount of water and a certain amount of air from the upper part of the condenser was acomplished in this condenser not in an economical manner. There was a compensating advantage in doing away with one complication of the condensing engine, namely the air-pump; but whether that advantage was not purchased at too great a price was a question which he should like to see more fully elucidated than was done in the paper at present.

He should also like to know what vacuum could be regularly maintained by this condenser; there seemed to him a difficulty in that respect. When the vacuum was produced in the auxiliary condenser, no doubt the water in the upper chamber by its own gravity fell readily into the lower chamber; but only a small portion of the air that was accumulated in the upper chamber would follow it; and in proportion as the lower chamber was small or reduced in comparison with the upper chamber or main condenser, in the same ratio the vacuum would be diminished in the upper chamber. It would be interesting therefore to know what was the vacuum that could be obtained currently with this condenser, and what was the amount of steam necessary to work it.

Mr. F. J. BRAMWELL could not help thinking that the introducers of this condenser had been troubled with difficulties as to the existing air-pump which were to a great extent imaginary. It was said that the existing air-pump was comparatively inapplicable to colliery

winding engines and other engines which had to stand for a time and then had to go to work, because the vacuous condition was not ready for them. It had been answered by Mr. Olrick that blowing-through was a simple and easy matter; but besides that, there were instances where there had been auxiliary engines for the purpose of maintaining a vacuous condition at all times. For example, the Blackwall Railway when worked by ropes was worked by marine engines, air-pumps for which were driven by a pair of auxiliary engines; and these being in action before the main engines were put to work, the main engines were always ready to start, and they themselves worked the air-pumps afterwards. That was another way of getting over the difficulty.

Another objection stated in the paper was the imaginary difficulty of having condensing engines working at a very high speed when working the air-pumps. This was purely imaginary, as was proved by the fact that in Mr. Thornycroft's steam launches, when used for torpedo purposes, where there must be no noise of waste steam up the chimney, the engines were worked at 500 rev. per min. with 26 in. vacuum; and there were very few cases where more than that was wanted. In their instance it was found the air-pumps could be readily worked direct off the engines at the same speed.

There was another mode of applying live steam and getting rid of water from the condenser, which appeared to him to be preferable to the one proposed in the paper; the mode to which he alluded was the Morton ejector condenser. If it were wished to use live steam for ejection purposes, he considered it had better be used in that way. That instrument was continuous in its action, without any valves of any kind, and the vacuum could always be got up before the engine was started. There, as a rule, the ejection was made by the momentum of the exhaust steam; but if a little live steam were added, those condensers became very efficient, and they were free from any moving parts whatever.

There was in use extensively in Scotland, and had been used for many years, a kind of condenser called the blow-through condenser; it was new to himself when he saw it at work five or six years ago. In many of the engines to which it was applied the steam was

expanded down to a pressure only a little above that of the atmosphere, and the steam was then allowed to exhaust into the condenser, driving out everything it found there with a rush. Then the outlet valve shut, and the injection being turned on, a poor vacuum was obtained.

It seemed to him that there was one considerable objection to the condenser described in the paper, which objection had been partly alluded to by Mr. Siemens. If the bottom vessel were made small, the proportion that it bore to the whole condenser represented the proportion in which the air would be taken out; the water would all go, but the air would go only in that proportion; and if the bottom vessel were made large, a considerable quantity of steam must be used. But whatever size it was made, whether the engine was hard at work or not, the same amount of steam had to be used every time, although the engine might be only lightly loaded. Whereas when the water and air were extracted by the air-pump, the air-pump only had a slight resistance to overcome at its starting; and setting friction out of consideration, the actual consumption of power to get rid of the air and water by means of the air-pump would vary with the work being done by the engine: whereas it seemed to him that in the plan now described the auxiliary condenser must necessarily be made of a right size for the largest amount of work that would ever come upon the engine, and the same quantity of steam must necessarily be expended at all times to work the auxiliary condenser, whether the engine was doing the full amount of work or not. That he should think in many circumstances would be a considerable disadvantage.

Mr. T. ADAMS observed that the question of the comparative economy of the ordinary condenser and the one described in the paper resolved itself into the simple one of the horse power required to work the air-pump, and the quantity of steam passing through the tappet-valve in order to produce the vacuum in this condenser. If that steam were applied in the cylinder, what horse power would it give off? The difference between the horse power given off in the cylinder and that required to work the air-pump would show the

balance either for or against the condenser. On previous occasions when the subject had been discussed elsewhere, this enquiry had been made respecting the condenser; and if an answer were given to it, the matter would be made plain and simple; hitherto it had not been shown.

Mr. PRESTON replied respecting the quantity of condensing water used in the condenser proper, that this was less than in the ordinary condenser in proportion to the amount of power required to work the air-pump; whatever that power was, so much less water was necessarily required in this condenser. Then it had been urged that this condenser was no more useful for winding engines than for any other sort, such as marine engines; but with regard to winding engines the reason was that the attendant was expected to have nothing to divert his attention, he had simply to look at the pit signals, and start and stop the engine accordingly. It was expected that he did not move from his place from the time that he had taken hold of the handles for working the engine; he had not time to go and turn any other tap or open any other valve, nor was it expected that he should do so. When the steam was turned on for starting, the winding engine was expected, for the sake of economy and prudence, to start immediately at about the speed at which it was going to work throughout the winding. In the ordinary condensing engine that was impossible, because there was not a vacuum to begin with; it was necessary to blow-through in order to make a vacuum, and that took time. With this condenser there was a vacuum ready, and the engine started at once the moment the steam had been turned on.

The quantity of steam required for working the auxiliary condenser was no doubt the main point in question. The correctness of the calculation given in the paper respecting this had been partially proved by facts showing that it took less steam altogether to work the engine and to work the auxiliary condenser than it took to work an ordinary condensing engine of the same power. The vacuum obtained with this condenser averaged from $12\frac{1}{2}$ to 13 lb. per sq. in. He believed from his own experience, and from what he

could gather from others who had closely watched the matter, that the natural vacuum for the condensing engine, minus the air-pump, was from 12 to 12½ lbs., and any more that was got from the ordinary condensing engine was due to the effect of the air-pump, which was a source of considerable expense.

With respect to the Morton ejector condenser, that was one that would only work when it had a head of water; and the great advantage of the condenser described in the paper was that it drew its own water from a lower level, like an ordinary air-pump condenser.

Mr. F. J. BRAMWELL said that was really not the case with the Morton condenser; when live steam was used from the boiler it would work without a head.

Mr. PRESTON said he had not seen it work in that way. In regard to blowing-through to form a vacuum, no blow-through was required in the condenser described in the paper; but if the engine had been standing for some time, and it was requisite to make a vacuum, it was done by turning a small handwheel at the end of the tappet shaft once or twice round, so as to admit a jet of steam and then a jet of water, and thereby create a vacuum; this was tantamount to the common plan of blowing-through, but for winding engines this was obviated by working the tappet shaft by a small donkey engine, thereby always ensuring a vacuum to exhaust into, the moment the engine started.

The size of the auxiliary condenser certainly had to be arranged according to its work, and that was a question not yet fully settled, whether its size was not in excess. He believed practically that the size considered requisite in the inventor's first attempts had been in excess of what was really required. It was quite evident that the size was wanted to be sufficient not only to hold the water discharged from the condenser proper, but also to take away the air that came along with the water and the steam. That could be modified by working the tappet shaft quicker, so as to open the steam and water valves

oftener, which would be one way of lessening the size of the auxiliary condenser; but it was found practically that about five times per minute was a convenient speed for working the tappet valves, though he believed one or two of the condensers that had been put down had been worked faster.

The PRESIDENT moved a vote of thanks to Mr. Preston for his paper, which was passed.

The following paper was then read:—

ON THE FRISBIE MECHANICAL FIRE-FEEDER AND GRATE FOR BOILERS AND FURNACES.

BY MR. BERNARD P. WALKER, OF BIRMINGHAM.

The object of this apparatus is to supply the fuel at the lower surface of the boiler and furnace fires, instead of at the upper surface as usual.

The apparatus is shown in Plates 50 and 51, in which Fig. 1 is a longitudinal section, Fig. 2 a front elevation, and Fig. 4 a plan. The grate is provided with a central aperture surrounded by fire-bars, as shown at A in the plan, Fig. 4, and by means of the mechanism to be described the fuel is thrust up through this aperture from beneath into the fire. The fuel is fed into a cylindrical box or hopper P P, which, swinging on pivots E E placed directly beneath the centre of the aperture in the grate, is provided with a movable bottom or piston F, and is charged with fuel when in the position shown in Fig. 3, the aperture being meanwhile closed by a curved plate or apron R attached to the upper margin of the cylindrical fuel box or hopper, thus retaining the fuel in the grate. The crank-shaft G being furnished with arms and crank pins I, taking into notches in the links H, which are pivoted on the supporting plates on which the hopper swings to and fro, is driven by means of a winch handle and wheel gearing M.

When the fuel box or hopper arrives at the extent of its swing, which brings its mouth directly underneath the aperture A in the firegrate, the crank pins I leave the notches, and the links H then rest upon the shaft, as shown in Fig. 1, and thus lock the hopper in its vertical position. The crank K, being provided with a friction roller, now comes in contact with the lever L, and by the continuous motion of the winch handle in the same direction raises it along with the piston F and the charge of fuel until the

surface of the piston is continuous with that of the apron or retaining plate R. The catch N now receives the end of the lever L, and keeps it with the piston in the position shown in Fig. 1.

The movement of the winch, and consequently that of the wheels and crank-shaft, is now reversed; and the crank pins of the arms I, taking into the notches in the links H, first disengage the ends of the links from the crank-shaft by raising them, and then bring back the hopper into its first position, as in Fig. 3. The catch N, striking a bar O which crosses the ashpit, allows the piston to fall ready to receive a fresh charge of fuel.

The firebars forming the grate and surrounding the central aperture are supported upon a circular frame running on friction rollers D D, as a turntable. In the periphery of the circular frame are holes, as shown at C, and by means of a lever inserted into these the grate is readily turned round, so as to bring its circumference in successive portions opposite the door B, to permit the removal of clinkers or other incombustible matter contained in the fuel. The successive charges of fuel through the central aperture push those portions that will not burn to the circumference of the grate. The ring of metal J, having its internal diameter slightly less than that of the central aperture A, is supported by four arms, which carry the friction rollers D D, and are fixed to the dead-plate. In those cases where access can be had to either side of the grate, as in glass furnaces &c., the fire is readily cleansed in the ordinary manner by striking the bars, and the revolving grate is dispensed with, straight bars being substituted, as in Fig. 7.

Fig. 5, Plate 52, shows the arrangement for a plain cylindrical boiler; Fig. 6 for a multitubular externally-fired boiler; and Fig. 7 for a glass furnace.

The system of firing by inserting the fuel from beneath, as effected by the apparatus described, presents several important advantages, some of which are as follows :—

First, the fire is not reduced in intensity by the cold fuel damping the flame, as is the case when the fuel is thrown on the upper surface of the fire; so that the evolution of smoke from this cause is completely avoided.

Secondly, each successive charge of fuel lifts up and most effectually "pokes" the fire.

Thirdly, the cooling of the furnace by the admission of a large volume of cold air when the fire doors are opened for stoking is avoided.

Fourthly, a smokeless flame is readily attainable with a thick fire, although using smaller fuel than can be employed in ordinary furnaces, whilst a maximum intensity of heat is attained.

The result is great economy of fuel with almost entire absence of smoke.

It is not professed that the principle of this furnace is new; but the arrangement of the mechanism described, which is founded upon the invention of Mr. Frisbie, claims to effect a considerable improvement on the ordinary method of firing, and to be a step towards economising fuel. This furnace has been in constant work for nearly four years at Spring Hill Rolling Mills, Birmingham, in muffles for heating copper and brass sheets, and for more than a year under steam boilers in this neighbourhood, and it has been in use eight months in a glass furnace in London; and all these applications have proved thoroughly satisfactory. It is found difficult to procure accurate statistics, so as to compare this system with the old as regards economy; but information from the persons using it leads to the conclusion that from twenty per cent. saving in cost of fuel in steam engine boilers, to sixty per cent. in reverberatory furnaces, such for instance as are used for smelting nickel, has been effected by its use, a less expensive quality of fuel being made available by this furnace. It is also found that the grate bars are far more durable than in ordinary furnaces, whilst the apparatus itself is not liable to injury from wear or to derangement in use.

Mr. WALKER exhibited a specimen of the mechanical fire-feeder, and showed its action in working. He stated that as much as 25 lb. of coal per sq. ft. of grate per hour had been burnt upon it. The coal was put into the feeding hopper by hand, but it had been proposed to alter the apparatus and make it self-acting; he was not quite sure at present whether it was worth the expense of doing so. The raising of the piston in the hopper made a little conical hillock of fuel in the centre of the grate, and the first effect of the heat on the coal that had been previously warmed in the upper part of the central chamber of the grate was that the coal burst into flame at at once, giving off gas instantly on being pushed into the fire.

The PRESIDENT observed that the apparatus could not be applied in the case of the Cornish boiler, except by firing the boiler externally instead of in the tube.

Mr. WALKER said that had been done with success, but with the disadvantage of the increased room that was required and the consequent difficulty of setting the boiler, which rather led him to discourage the use of the plan for such boilers. In the case of the first grate so applied there was destruction of the bottom plate of the boiler, in consequence of the deposit at the bottom of the boiler which was liable to occur in such cases; but in other similar instances the grate had now been tried for more than two years, and the result had been that there was no portion of the boiler damaged. He considered that the chief value of the grate was in furnaces where a large volume of flame was wanted and consequently a thick fire, as in muffles and glass furnaces; there its success had been remarkable.

Mr. L. OLRICK asked whether the absence of smoke was complete without introducing any air above the grate; he did not see any arrangement shown in the drawings for the admission of air above the grate, and concluded therefore that the whole of the air required for the perfect combustion of the coal entered through the grate bars. He enquired also if the grate was always made circular, whether applied to Cornish or vertical boilers.

It was stated in the paper that each successive charge of fuel lifted up the fire, and most effectually poked it; and he could understand that the fresh fuel coming up in the centre of the fire would push the coal radially over every part of the grate; but he did not see how the effect of that fuel coming up in the centre could be to poke the fire. By poking the fire he meant that any clinkers that might be collected on the grate would be removed; and he hardly saw how clinkers could be removed by the mere fact of the fire being lifted up in the centre; it often took very hard breaking to remove the clinkers in ordinary grates.

He should also be glad to know whether the proportion of air spaces in the grate bars was always maintained the same, or whether the air spaces were altered in size according to the kind of fuel intended to be used. Also why it was considered that these grate bars lasted longer than the bars in ordinary furnaces. He had no doubt that the apparatus was a very good one; and enquired what was the cost of a grate of the size shown in the drawings.

Mr. M. H. SMITH asked if any difficulty was experienced from the charge of coal that was pushed up by the piston into the central chamber of the grate ever coking too hard, and so adhering to the sides of the chamber. The chamber of the feeding hopper in which the piston worked was of course made cylindrical, with parallel sides, and the fixed chamber in the grate above it appeared to be also made with parallel sides; if it were made slightly conical, expanding upwards, he conceived the coal in the case of coking hard would be more readily pushed up. Again he should be glad to know whether there was any loss of coal in case of firing too fast. If it were wanted for instance to push up two hoppers of coal at once, did not the coal then rise before it was coked; and in that case did the dust fall through the firebars—the openings of which he observed were rather large—before it was coked. Also as all the air for the combustion of the coal must necessarily go through the firebars, and as the coal was fed up in the centre, the outer rim of the bars must be more free for the admission of air, and he should imagine the combustion would be more intense at the outer rim. He enquired whether that more

intense combustion at the outer rim affected the durability of the firebars in that portion of the grate more than in any other part.

Mr. F. J. BRAMWELL observed it had been stated in the paper that the principle of firing from below was not a new one; and the object of the paper was simply to recommend this particular apparatus for carrying out that principle. He might mention that thirty years ago there was at work in Woolwich dockyard a wagon boiler driving one of Maudslay's engines, the firegrate of which boiler was fitted with a mechanical feeder introducing the coal from below; he did not know whose invention it was. The fireplace was nearly square, and in the centre of it was a rectangular opening, instead of a circular one; beneath the rectangular opening was a box, which had in it a rising and falling piston, worked by a rack and pinion, and immediately above the body of the box was a tranverse sliding plate. Assuming the piston to be up, having just raised a charge of coal into the fire, the sliding plate was then pushed across above the piston, and that plate held up the fire. The piston being then lowered, a door in one side of the box was opened, the whole of the box was filled with coal, the charging door was shut, the sliding plate was drawn out, and then the piston was gradually raised by the rack and pinion, pushing up the coal into the fireplace, the bars of which were made like the sides of a hopper, sloping upwards and outwards from the central feed opening; he did not know why that arrangement of the bars was adopted, but he thought it must have had the effect of making the dust fall through the sloping sides, and also of making a thin fire at the edge of the grate. That mode of firing gave a beautiful smokeless flame, and the combustion appeared to be complete; but there was intense heat immediately above the central part of the fire. That apparatus was in use, as he had said, thirty years ago, and he did not know why it had been abandoned, unless it was that there had been some difficulty from the fuel in the box becoming ignited.

It was well known that if it were wanted to get a fire to burn well in a firegrate of a house, on a day when much heat was not wanted, the best way was to lay the fire with the wood upon the top,

then lay a little coal on the wood, and light at the top. A fire so lit in the morning would last eight or ten hours, giving about as much heat as might be required in the autumn and in the spring.

He had been so much struck with the plan that he had seen at Woolwich, and so much of opinion that the right way of firing was to fire from below, that an abortive attempt had been made many years ago by himself and his fellow apprentice, Mr. Homersham, to employ a hollow shovel with a sloping top like the roof of a house, and a sliding plate for the bottom, with two handles; the shovel was turned upside down and filled, the plate was slid over it, and then it was turned the right way up, containing the charge of fuel. Then it was endeavoured to insinuate the shovel underneath the fire, and withdrawing the bottom plate to deposit the charge of coal on the bars. The violent exertion required to work it however proved altogether beyond the strength of the stoker; and it became evident that the plan must be given up. He was an advocate for the introduction of the principle of firing from below; and he thought the apparatus described in the paper was one that would fulfil that mode of firing.

Mr. WALKER said, with regard to the consumption of smoke, the mechanical fire-feeder described in the paper was quite satisfactory in cases of thick fire; but where the men were careless, and, the firegrate being perhaps too large for the work that was done, two or three charges were put on too quickly, so that the fresh coal was lifted through the mass of the fire, then the fire did give off smoke. If the quantity of fresh coal supplied by the feeder was proportionate to the size of the fire, no smoke was formed except when the fire was being cleaned of clinker. If there was an excess of air going through, that would generally occasion smoke.

With regard to the shape of the grates, they had been made for glass furnaces generally about 5 feet square, instead of circular.

The pushing up of the charge of fuel into the fire was not attended he believed with any particular difficulty. In the grates first made the sides of the central chamber had been made parallel, and the consequence was that some kinds of coal got jammed in it.

The coal did not cake till it had got on to the firebars; and the effect of caking was not to increase but to reduce its bulk. It had now been found necessary to make the centre chamber conical, enlarging it from 16 in. diameter at the bottom to 20 in. diameter at the top in the height of 9 in.; in the specimen exhibited the amount of cone was rather less and was scarcely sufficient. The effect of lifting the piston of the charging hopper was that the charge of fuel contained in the central chamber was lifted up to the surface of the grate and insinuated itself underneath the burning fuel; and jets of gas were at once seen issuing from it in all directions. The power required to be exerted in charging the grate was really dependent on the proportioning of the gearing, which was varied according to the quality of the coal. In the grate exhibited, which was intended for open free-burning coal like that of South Staffordshire, the power required would be very slight, and the handwheel was therefore arranged to make only seven turns for performing the entire operation. But in the glass furnaces at St. Helen's, where caking coal was used, the pinion had to be made smaller to get the required power, and it took eleven turns of the handwheel to effect the charging.

With regard to the durability of the firebars, the segment exhibited had just been taken out of a furnace after twelve months' work under a steam boiler; and the amount of wear on it was seen to be very little indeed. In these grates applied to nickel-smelting furnaces one set of bars lasted ordinarily nine months, continuing all that time in perfect condition for use; they then required to be renewed certainly, but they were not utterly destroyed, as was the case in three months with the bars in the ordinary grates. The bars were so cool in working that the hand could be placed on the outer edge of the grate while the fire was burning, the heat not being so intense round the outside as towards the centre of the fire; and the bars kept cool because it was cold fuel that was next to them. The air spaces were adapted to the quality of the fuel; in the North of England some of the grates had been made with only $\frac{3}{8}$ inch spaces, much finer than the bars exhibited, and for other districts some had been made with spaces as much as 1 inch width, as in the case of the Wigan caking coal. The admission of air was usually found

sufficient when it entered through the bars; but in other cases the firedoors were made with perforated plates, as shown in Fig. 2, and the length of flame was considerably increased by their use.

With regard to the question of price, that was more a commercial matter, and of course it must depend mainly upon the royalty; the work itself was of an inexpensive kind. A large grate about 4 ft. diameter weighed about 2 tons complete; the price would vary with the price of the iron, and would range from £30 to £40, irrespective of royalty.

The formation of clinkers was rather different in this grate from that in ordinary fires. The combustion taking place from the top downwards, the clinkers here ran on the top of the fire, instead of upon the bars; and the next charge rising from underneath the fire broke them up to a large extent. The circular rotation of the grate at intervals by means of the hand lever caused the dust to fall through upon the bedplate beneath.

With regard to the earlier apparatus at Woolwich, to which attention had been called by Mr. Bramwell, he was aware of the existence of that machine, and believed the reason why it was given up was that there was sometimes difficulty in pushing the sliding plate in through the coal; the plate running in a groove, its edge would occasionally meet a piece of coal and it would be jammed. That was avoided in the grate now described, because the surface of the curved dead-plate supporting the coal in the charging chamber was made continuous with that of the piston when in its highest position.

As to the general principle of supplying coal to a fire from below, he thought it was very obvious that was the correct plan; no one would think of lighting a tallow candle and then inverting it. The principle of the introduction of the fuel at the bottom seemed to be very satisfactorily carried out by Mr. Frisbie in this grate. In the United States there was scarcely a glass house in use in which this grate was not adopted; and the successful introduction of the grate there some years ago had induced him to undertake the manufacture in this country.

The PRESIDENT moved a vote of thanks to Mr. Walker for his paper, which was passed.

The following votes of thanks were then moved by the President and passed :—

To the Council of the Midland Institute, for so kindly granting the free use of the Lecture Theatre, for the Meeting of the Institution.

To the Local Committee, for the excellent arrangements that had been made for the Meeting.

To the Proprietors of the several Works visited during the Meeting, for their kindness in opening their works to the Members.

To the Railway Companies, for the special facilities and privileges granted for the Excursions.

The Meeting then terminated.

EXCURSIONS.

On Tuesday afternoon, 18th July, the Members visited Nettlefolds' Screw Works at Smethwick, where the process of manufacture of wood screws was shown. The length of wire to form the screws is cut off by machines, which also upset one end by a blow to form the head. These "blanks" then pass to a machine in which the head of each is turned, the blank being held in a revolving chuck, and the tool brought up to it, and the nick is then cut across the head by a small circular saw; the supply of the blanks to the machine is by a self-acting feed, and the chuck holds and releases the blank by self-acting means. After being sorted and examined, the blanks next pass to the screwing or "worming" machine, in which each is gripped by the head end in a revolving

jaw; and after the other end has been turned off to a point by one tool, the thread is cut by a traversing tool, taking a succession of cuts of increasing depth. As soon as completed, the jaw is opened to release the screw, and takes hold of a fresh blank by self-acting means. The finished screws are cleaned by washing in revolving riddles with a strong solution of soda, and then dried in shakers, sorted, examined, and packed. The screwing shop covers about $1\frac{3}{5}$ acres, and contains upwards of 2000 machines, turning out altogether about half a million screws per hour; the machines being self-acting, one woman can attend to several of them, having only to supply the hoppers with blanks and to change the cutters as they become worn.

All the machines and tools used are made at the works, and special precautions are taken to ensure accuracy and uniformity in shaping the cutters required for so large a number of machines. These are formed out of steel rings, turned exactly to standard dimensions and then divided into segments, each of which is used as a tool after having been hardened and ground: accuracy of angle in the grinding being ensured by fixing the cutter in a slide-rest that traverses across the face of the grindstone at the correct inclination. The small circular saws employed for cutting the nicks in the screw heads last on the average for cutting about 1000 screws each, and consequently a fresh supply of 4000 to 5000 saws per day is required. The saw blanks are stamped by a press out of a strip of steel, and 150 of them are compressed together on a mandril; the whole block is then turned cylindrical, and placed in a vertical slotting machine, having a number of cutters. The saws are then hardened and tempered; and those that have been used up once are softened and re-cut a second and third time.

The works comprise also a wire mill, a bolt and nut mill, and a nail mill, in the last of which are made spikes and staples &c. out of wire bent cold at one operation, at the rate of from 90 to 360 per minute according to the size. The driving power of the works consists of two pairs of Corliss engines, with 28 in. cylinders and 4 ft. stroke, running at about 58 rev. per min.; and a pair of horizontal compound engines with 22 in. and 36 in. cylinders, and 3 ft. 6 in.

stroke; and two pairs of horizontal condensing engines with 24 in. cylinders and 3 ft. 6 in. stroke. The Members were entertained at luncheon at the works by Mr. Nettlefold.

Messrs. James Watt and Co.'s Engine Works at Soho were also visited by the Members, where four large pumping engines for the South Staffordshire Water Works were seen in process of construction, and a pair of pumping engines with 27 in. cylinders and 3 ft. stroke for the Equilmalt Graving Dock in British Columbia; also several engines of various sizes for London breweries, and a compound beam engine for the Worthing Water works.

On Wednesday afternoon, 19th July, the Members visited the Small Arms Factory at Small Heath, and the processes of manufacture of the Martini-Henry rifle &c. were shown. The forgings are made in dies under steam stamps, steam hammers being employed for the larger work, such as the steel breech-bodies of the Martini-Henry rifle; these are first forged solid in a die, and then punched hot from each side, leaving only a small fin as waste in the centre of the hole. The bodies are shaped by a series of revolving cutters, taking both sides at once; and similar cutters or "milling machines" are used for shaping the other portions of the work; several hundreds of these machines are employed, acting upon the copying principle, and by this means details of the most complex shapes are finished almost without being touched by hand, and all the work is made in exact duplicate and interchangeable. The shaping and recessing of the gunstocks is performed in a number of successive operations by a series of copying machines.

In the boring of the barrels, after being bored out near to the gauge, they are finished by long square steel rimers ground very

truly with two cutting edges, and packed with a thin wood strip and one or more liners of paper: the rimering being repeated if necessary, with an additional liner of paper interposed between the rimer and the wood packing-strip. The barrels are set by hand, if not perfectly straight after boring; and are then rifled by a series of very fine cuts of a rifling tool, which takes from 5 to 20 cuts for each groove in succession.

In the museum of the factory were shown specimens of the different varieties of rifles and other small arms, with sets of details of the separate parts, and the gauges used in their examination.

On Wednesday evening a number of the Members and their friends dined together at the Royal Hotel.

On Thursday, 20th July, an Excursion was made by the Members by special train to visit the Sandwell Colliery near Birmingham;—Earl Dudley's Lye Cross Colliery;—the Hailstone Quarry of Mr. T. P. Jones near Rowley;—Earl Dudley's Round Oak Iron Works;—and Messrs. Cochrane's Woodside Iron Works, near Dudley.

The Sandwell Colliery is situated on the Great Western Railway, 3 miles from Birmingham, on the eastern boundary of the South Staffordshire coalfield, and underneath the lower new red or permian formation. Until the present company undertook to prove it, no trial sinking had been attempted, though several borings had been put down during the last half century; none of them however were carried deep enough to prove coal or even coal measures, and great interest attaches consequently to this undertaking, which has succeeded in proving the Thick coal in that locality. One borehole put down forty years ago, half a mile east of the present

pits, was carried to a depth of about 220 yards, and then abandoned; but experience has now shown that had it been carried a little deeper the coal measures must have been struck. It was not till 1870 that the Sandwell trial sinking was started, on the proposal of the present engineer of the company, Mr. Henry Johnson, and in 1874 the Thick or Ten-Yard coal was reached, and was found to be 6 yds. 2 ft. 6 in. thick. The second shaft was then commenced, and reached the coal in $1\frac{3}{4}$ years. The first or trial shaft had been sunk under many difficulties, sometimes with every prospect of success, and at others with almost every hope gone; but being persevered with through good report and ill report, it resulted in the present success.

The first pit is 10 ft. diameter and 440 yds. depth to the bottom. The Thick coal was reached at 418 yds., and the present inset is at 423 yds. The drivings or explorations made in this pit while the second shaft was being sunk extend about 1,000 yds. to the north, 60 yds. to the south, 300 yds. west towards the old coalfield, and about 200 yds. east towards Birmingham; over this area the coal is found to be about 8 yds. thick, having a dip due east of about 1 in 7. The second pit is 15 ft. diameter, belled out at the bottom to 20 ft. and groined into a brick archway, which is 20 ft. wide and 16 ft. high, for four lines of tramway. This pit will be worked with two steel ropes $1\frac{1}{4}$ in. diameter, and double-decked cages, each cage carrying four tubs with 15 cwt. of load in each, making 3 tons of coal raised per trip. The cages will be guided by six wire-rope conductors $1\frac{1}{2}$ in. diameter.

The winding engines are a pair of horizontal high-pressure direct-acting engines, made by Messrs. Coupe of Wigan, having 36 in. cylinders with 6 ft. stroke, double-beat equilibrium valves, and 18 ft. drums. There are eight plain cylindrical boilers, 5 ft. 6 in. diameter and 40 ft. length, with hemispherical ends, fitted with feed and steam indicators in duplicate, and fed by a pair of donkey pumps; the stack is 8 ft. square inside throughout and 203 ft. high. A tunnel 5 ft. high, passing from the neighbouring railway cutting underneath the boilers and engine house, contains all the blow-off pipes from the boilers, and serves as a drain. The pit frame or head

gear to the 15 ft. pit consists of four uprights 60 ft. high, and two sloping legs 72 ft. long, of pitch pine 16 in. and 14 in. square, well braced together and carrying a pair of 16 ft. pulleys. A high-pressure hauling engine with 18 in. cylinder is fixed to work an endless-chain tramway to a wharf on the Birmingham Canal about 600 yds. distant, and the colliery has also communication with the Great Western and North Western Railways.

The water at the colliery is now very little, only about 50 gall. per min., but in sinking the first shaft it was about 250 gall. per min.; the pumps lifting 230 yds. are in three sets, all bucket lifts, with working barrels 13 in. and 14 in. diameter and 6 ft. stroke; they are worked by a condensing beam engine with 45 in. cylinder and 5 ft. 6 in. stroke, supplied with steam by three double-flued Cornish boilers 7 ft. 6 in. diameter and 30 ft. length.

The Lye Cross Colliery is situated nearly in the centre of the basaltic mound constituting the Rowley Hills, to the south-east of Dudley, and forming a continuation of the chain of silurian hills, consisting of Sedgley, Wren's Nest, and Dudley Castle.

The starting of this colliery was the first attempt to sink through the basalt, to win the coal known to be lying beneath (although at two neighbouring collieries workings had been previously carried under the basalt), and was an undertaking of considerable magnitude, as it was not known what thickness of basalt covered the coal measures. The sinking has proved thoroughly successful, the thickness of basalt being considerably less than was supposed, only 68 yards of basalt having to be sunk through before the rock forming the upper portion of the coal measures was reached; and 92 yards further down (or 168 yards from the surface) the Two-foot and Brooch coal seams were struck, and 50 yards lower the Thick or Ten-Yard seam, and below that the other seams in regular succession, as in other parts of this coalfield. The basalt was followed by 10 inches of natural soil of a dark colour, and under this was the ordinary red brick-clay usually found in the district as the surface clay.

The Rowley hills owe their origin to an outburst of basaltic lava (whose funnel, or point of emergence from below, has however not yet been discovered) having spread over that portion of the coalfield, and protected it from the denudation which elsewhere removed some of the upper portion of the carboniferous strata. Dykes and sheets of intruded igneous rock occur between the coal seams in some places, similar to the basalt, except that there has been more or less mutual reaction between the molten basalt and the coal measures, whereby the former has become "green rock" and "white rock," according to the nature and extent of the change it underwent whilst cooling, and the coal has become charred for several inches distance from the basalt.

The coal measures of the Staffordshire coalfield were deposited on a floor of silurian rocks, peaks of which are seen protruding through the coal measures at Sedgley, Wren's Nest, and Dudley Castle, and are quarried for the silurian limestone of which they consist. The actual extent of the Staffordshire coalfield is not definitely proved; and, as sinkings to the east of the formerly supposed boundary of the coalfield have proved that it extends further and further eastwards, under the permian rocks, there seem some grounds for supposing that it will ultimately prove to be continuous with the Warwickshire coalfield.

The sinking of the Lye Cross shafts was commenced in August 1872 and completed in July 1874. The downcast shaft is 12 ft. 6 in. diam. in the clear, and the upcast 8 ft.; they are sunk through the coal to a depth of 13 yds. below the coal before forming the "insets," which are at the right level to meet the coal (which forms a saddle, dipping in both directions from the shaft) at sufficient distance to support the shaft firmly, namely 100 yds. from bottom of shaft. The insets are 13 ft. high and 25 ft. width, with four lines of rails, for some distance from the shaft. Gate roads have been driven in different directions to the extent of 3 miles. The upcast shaft is sunk to the same level as the downcast, but the air drift follows the rise of the coal; the shaft has a brick continuation about 40 ft. high above ground. Wire-rope guides are used, with screw adjustments at top and bottom.

The thickness of the various strata passed through in sinking the shaft was as follows:—

	Yds.
Made ground and surface soil	8½
Rowley Rag or Basalt	68
Rock and Binds	91½
Two-foot and Brooch Coal	2
Rock and Binds	48
Thick or Ten-Yard Coal	10
Gubbin Ironstone	3
Heathen Coal	2
Whitestone Rock and Measures	7½
Pennystone Measures	3
New Mine Coal	1
Fire Clays and Binds	13
Bottom Coal	1
	258½

The first 3 yds. of the Rowley Rag was partially decomposed, and the rest was in the form of very large boulders, the outside crust of which was in many cases much decomposed. When this bed was nearly passed through, a large quantity of water was met with, which suspended sinking operations for about three weeks. As the coffering for keeping back the water was required to extend to a depth of 75 yds., and there was no sufficient foundation for it, 4 ft. headings were then driven into the sides of the shaft, and six large oak timbers inserted to form a seating for the curb to rest upon, and the coffering made with hydraulic lime effectually kept back the water; this lime was a mixture of black and white lime, coke-dust, and clinkers (without ash), ground in a mortar mill, mixed with water, and applied hot. The brickwork of the shaft is 2 ft. to 3 ft. thick in some portions. The water from behind the coffering is carried down into the pit by a pipe under sufficient pressure for feeding the underground boiler; it also supplies two drinking fountains for the men. The water is remarkably pure and fresh for drinking; when first drawn it contains a large quantity of

minute air bubbles, giving a milky appearance to the water, which gradually escape.

The roads in the pit are very wide and high, and heavily timbered with oak 16 × 14 in. Underground is a manager's office where the men are paid, a dining room for the colliers, and stables for the pit horses.

The winding engine is horizontal, with a pair of cylinders, 26 in. diam. and 6 ft. stroke, working to about 240 H. P. The winding drum is 14 ft. diam. parallel, and is fitted with a powerful differential steam break, which is worked by the ordinary foot treadle, and dispenses entirely with the ordinary break. Round wire rope is used 1 in. diameter. The pit frames are 45 ft. high, with pulleys 14 ft. diam. The boilers are three in number, plain cylindrical, with hemispherical ends, 5 ft. 6 in. diam. × 39 ft. long, and working at a pressure of 40 to 50 lb. per sq. in. An underground engine is used for hauling coal up an incline of 17 in. per yd. or nearly 1 in 2 from the lower workings to the bottom of the shaft; horizontal engine, with 15 in. cylinder, 3 ft. stroke, winding on a 6 ft. drum with a round wire rope. Steam is supplied by an underground boiler, plain cylindrical with hemispherical ends, 4 ft. 6 in. diam. × 32 ft. long, working at 50 lb. per sq. in. The flue of this boiler passes into the upcast shaft, thus forming the furnace for the ventilation of the mine; but an auxiliary furnace is provided, which can be used to assist the ventilation if required.

An electric signal is used from the pit bottom to the engine room at the surface, and from the underground winding engine to the bottom of the incline, worked by a Leclanche battery. In any case of a tub getting off the rails on the incline, the two electric wires are arranged to make contact and give a signal for stopping the hauling engine, so as to prevent damage to the road.

The colliery is worked on the pillar and stall system, with pillars 10 yds. square, and stalls 8 to 9 yds. wide. A stall about 80 yds. long by 8 yds. high was shown specially illuminated, presenting a striking scene.

The Members were entertained at luncheon at the colliery by Mr. E. Fisher Smith.

At the Hailstone Quarry, situated on the slope of the Rowley Hills, basalt or "Rowley Rag" stone is worked on an extensive scale, with a face of about 75 ft. height extending $\frac{1}{4}$ mile length. The basalt is of a very compact character in this quarry, and does not show a columnar structure. The blasting is done with gunpowder in preference to dynamite, the latter having been found to shatter the stone to a greater extent, and cause a larger proportion of slack. The stone is broken by heavy hammers into squared blocks of various sizes for use as pitching and kerbstones &c., and the slack is broken up for road metalling.

At the Round Oak Iron Works, three of the Casson-Dormoy puddling furnaces fired with coal were seen in use, and another fired with gas. The rabbles are worked by mechanical means; and air heated by passing through a wrought-iron casing surrounding the furnace stack is forced in through the grate by a blower, and in the gas furnace a further supply is passed through passages in the crown and bridge wall, and delivered at a high temperature to meet the gas on entering the puddling chamber, producing an intense flame, the quality of which is regulated by adjusting the supply of air. The gas is generated in a producer at one end of the furnace, to which screened slack is supplied from a hopper by a fluted feed-roller. The pig iron has a preliminary heating between the puddling chamber and the stack; and the waste gases are utilised by passing through a horizontal boiler fixed above the furnace for generating steam.

The forge boilers are fired by Henderson's mechanical stokers, supplied with the smallest refuse slack direct from the pits. The slack is discharged from trucks into the hoppers of the stokers,

from which it is delivered by a feeding roller on to a pair of rapidly revolving horizontal discs, having projecting blades that distribute the slack over the fire in a finely divided and uniform shower.

At the Woodside Iron Works, a quantity of bridge work, roofing and railway iron work, was seen in progress, and in the pipe foundry the casting of some large mains of 36 in. and 40 in. diam. for the Manchester Water Works. At the blast furnaces a pair of Cowper's regenerative hot-blast stoves were seen in progress of construction, being the first erected in South Staffordshire; they are 21 ft. diam. and 57 ft. high, and the firebrick regenerators about 45 ft. high. The wrought-iron casings of the stoves are erected without scaffolding, by means of a circular platform inside, suspended from the shell itself by several Weston's pulleys: the pulleys being shifted up one by one when a new ring of plates has been added all round, the platform is then hauled up after them. A circular projecting rail runs all round the top of each stove, from which is suspended a light travelling platform, for convenience of examination if required. The blast furnace to which this pair of stoves is to be applied is closed at the top with a bell and self-closing gear, and the materials are raised by a pneumatic hoist worked by the pressure of the blast.

On Friday, 21st July, an Excursion was made by the Members by special train to visit the Dudley Port Limestone Pit of Messrs. Dixon and Burne;—Messrs. James Russell and Sons' Crown Tube Works at Wednesbury;—and the Needle Works at Redditch of Messrs. Henry Milward and Sons and Messrs. Samuel Thomas and Sons.

The Dudley Port Limestone Pit has great interest attached to it, as being one of the several places where the Dudley or Wenlock limestone has been extensively worked below the coal measures of the South Staffordshire district. Previous to the first opening of this bed of limestone at Dudley Port, the only means of supplying the blast furnaces with limestone for smelting purposes was confined to the outcrop of the Wenlock beds at Dudley Castle, Wren's Nest, and in the neighbourhood of Walsall. Since the sinking to this bed by Jeavons about the year 1825, there have been several successful deep sinkings in different parts of the coalfield. The Wenlock limestone is described by Jukes as forming "two bands of solid concretionary and flaggy limestone, with many calcareous nodules, concretions, and small flaggy beds, both between, above, and below them. It contains innumerable characteristic fossils; indeed the quarries of Dudley are the most famous in the world for upper silurian organisms; shells, corals, encrinites of very numerous genera and species, and trilobites, are all in a state of perfection, such as no other locality in Britain exhibits."

At Messrs. Dixon and Burne's pit, Dudley Port, the depth from the surface to the bottom of the Thick coal is 123 yds., and at a depth of 186 yds. below the surface the coal measures rest slightly unconformably upon the Wenlock shale (locally called "bavin"). This shale or bavin, intermixed with inferior limestone, is 34 yds. thick, making a total depth of 220 yds. from the surface to the top of the grey or thin limestone; thus the bavin forms the roof of the limestone workings. This grey or thin bed, which is used principally for smelting purposes, is the same as that exposed in the escarpment round the Dudley Castle and Wren's Nest hills. About 33 yds. below this bed lies the blue or thick limestone, which is from 10 to 12 yds. thick, and is used for making lime for building and agricultural purposes. This latter bed is not usually worked, the Earl of Dudley being the only producer of it in this district, and that only upon a small scale.

The grey or thin limestone, in which the workings visited are situated, is from 8 to 12 yds. thick, and for the most part excessively hard and crystalline, containing in places fine specimens

of crystallised spar. The bed is worked on the "pillar and stall" system, with pillars 14 yds. square generally, but considerably less in some places, and stalls 14 yds. wide, the full thickness of the bed being worked in one face by blasting off successive portions from the bottom upwards, ladders being used to reach the upper parts. The thickness of the seam varies suddenly in some places: the seam being apparently folded back on itself at one part, thus changing the thickness suddenly from 8 to 12 yds. Springs of fresh water, pleasant to drink, occur in places in the workings; and water is now filling the lower workings and rising slowly, so that pumping is expected to be required before long.

The shaft is about 240 ft. depth, and partly lined with brickwork; winding engine, an old tappet-motion beam engine; flat hemp rope, with iron cage containing a single iron skip for limestone. A second shaft is used for raising water by an iron bucket, having a self-acting valve at bottom, which discharges the water into an iron launder run across the pit mouth.

The limestone is nearly level throughout these workings, instead of the high inclination, fully 45°, of the limestone at Wren's Nest, which has consequently to be worked in galleries at different levels below one another. The excavations of this pit have occupied the last 25 years, and extend over an area of 15 acres, presenting a remarkable effect when illuminated, from the large dimensions and great extent of the excavations.

The workings were shown specially illuminated on the occasion of the visit, and several blasting shots were fired.

At Messrs. James Russell and Sons' Crown Tube Works, Wednesbury, the Members were shown the manufacture of wrought-iron tubes butt-welded and lap-welded. The tubes are made from flat strips of plate, or "skelps," first bent up hot into a rough tubular form by a squeezing machine, one portion at a time, or by drawing through a die which bends up the whole length of the skelp at one operation; the rough tubes are then heated for welding.

The butt-welded tubes are drawn out of the furnace at a welding heat through the jaws of a pair of draw-tongs with a circular opening, by which the weld is closed, half the length of the tube being welded at one heat, and the other half at a second heat; the tubes are straightened by rolling upon a table under the pressure of a heavy reciprocating plate. Small tubes are made by this process up to 12 ft. length; and for the manufacture of heating or refrigerating coils and still-worms successive lengths are welded together end to end. Coils are made of as much as 450 ft. length, the tubes being tested by hydraulic pressure both before and after coiling, as the coiling puts a severe strain upon the weld.

In making lap-welded tubes, which are made of larger diameters up to as much as 16 in. diameter, the skelps are bevelled at the edges, and welded by drawing out of the furnace through a pair of rolls with semicircular grooves, forming a circle of the required diameter for the tube, in the centre of which is the head of a long mandril, and the welding is rapidly effected by the compression between the mandril head and the rolls. The mandril is of slightly smaller diameter than its head, which is loose upon it; and when the welding is completed, the head falls off, and the mandril is then readily withdrawn from the tube. In the smaller sizes of lap-welded tubes the skelps are drawn through a die, which bends them into shape and effects the welding in one operation. Steel tubes are also made in the same way as the iron tubes, extra care and skill being applied to secure good welds. The furnaces throughout the works are all fired by gas supplied from a set of Siemens gas producers.

The straightening of the larger sizes of tubes is done between three rolls revolving together and rather longer than the length of the tube, which is laid longitudinally between the rolls, and straightened by gradually screwing down the top roll to press upon it as it rotates. Short curved elbow pipes of small size are bent in dies under a stamp, and larger sizes in a screw press; plain and flanged sockets for screwing or welding upon the ends of the tubes are also shaped under stamps. The testing of the tubes is done by 70 lb. steam for the gas tubes, and for the steam tubes by hydraulic pressure to a minimum of 500 lb. per inch.

The Members were entertained at luncheon at the works by Mr. Joseph Smith.

At the Redditch Needle Works the series of processes in the manufacture of needles was shown. The steel wire is supplied in coils from 1200 to 3000 yds. length each, according to thickness of wire, varying from $\frac{1}{22}$ in. to $\frac{1}{100}$ in. for sewing needles; and the following are the successive processes.

Cutting into lengths of 2 needles each, in bundles cut by hand-shears or cut separately in self-acting machines.

Annealing in a furnace in bundles held together by a pair of rings 3 in. to 5 in. diameter.

Rubbing for straightening whilst hot from the annealing furnace; by rolling the wires over one another by hand pressure on an iron table whilst remaining in the rings, the wires are made to straighten each other.

Pointing on grindstones of special quality from Frankfort, running at high speed, the wires being made to rotate whilst grinding, formerly between the hands of the workman, now between two india-rubber bands travelling over a grindstone with concave face; the steel dust from the grinding, formerly very injurious to the health of the workmen, is now all removed by an exhausting fan through a pipe leading from each grindstone. The wires are pointed at the two ends successively.

Stamping the gutter for the eyes by a falling die worked by the foot; forming the heads and marking the position of the eyes of the two needles in the centre of each wire.

Piercing the eyes by a pair of punches in a hand screw-press; these punches are of special delicacy in make and adjustment.

Tool making for the eyeing processes, of special interest.

Spitting or threading a number of the needles upon a pair of fine wires.

Filing to remove the burr made in stamping the heads.

Breaking the needles apart at the thin fin left between their heads.

Heading, rounding the heads by filing, special care being required to avoid weakening the eyes.

Hardening, by heating the needles in small iron trays, and dropping them into oil, care being taken that the needles are separated in the act of dropping, to ensure each being hardened.

Tempering, by heating on a hot plate or in a stove to the required temperature.

Hammer-straightening by hand on small anvils, to remove any warping caused by hardening.

Scouring, by making a roll of needles mixed with soft soap, emery, and oil, and wrapped in strips of canvas tied up at the ends, making rolls about 2 ft. in length and 3 in. diameter, which are then rolled backwards and forwards under runners worked by cranks driven by the engine; the process is continued for 8 hours, the needles getting scoured by rubbing against one another. This process is repeated from 2 to 8 times, according to the quality of the needles the finishing scouring being with putty powder. The needles are washed in soap suds after each scouring.

Evening and heading, to arrange the points all one way, by a dexterous motion of the hand, after shaking the needles parallel in a small tray.

Picking, to pick out defective needles with imperfect points or eyes, or not perfectly straight, etc.

Blueing, to soften the eyes by traversing the needles over a gas flame.

Drilling, for "drilled eyed" needles, to smooth the eye on each face, by a fine countersink drill: the preparation of the drills being a matter of great nicety.

Burnishing, by stringing the needles on horizontal wires carried upon a frame that has a reciprocating movement, giving a constant swinging motion to the needles that smooths the eyes by the rubbing on the wires, which have serrated surfaces.

Grinding for finishing the heads and points, on small grindstones running at very high speed; a number of needles are held

in a single layer, and rolled together between the finger and thumb of the workman.

Polishing, by a similar process on emery buff rollers.

Papering and Packing for sale.

The manufacture of needles for the world is carried on mainly at Redditch in England and Aix-la-Chapelle in Germany.

The Members were entertained at luncheon by Messrs. Milward.

On Saturday, 22nd July, the Birmingham Corporation Sewage Works at Saltley were visited. These works were constructed and carried out from the designs and under the superintendence of Messrs. T. and C. Hawksley; the sewage farm in connection with them occupies an area of 266 acres of land in the Tame Valley. The sewage delivered by the two main sewers is treated with a mixture of lime and water to the extent of from 12 to 14 tons of lime per day, the mixture being made in two large circular tanks with revolving stirrers driven by an engine; the water used is pumped up from the main sewer. After this lime-water is poured in, the sewage flows on 1-3rd mile further through the sewers to their outlet, and during the passage the lime becomes thoroughly blended with the sewage, and produces a flocculent condition of its solid contents, causing the heavier portion to sink rapidly to the bottom of the large settling tanks, of which there are two, worked alternately, each 330 ft. long, 90 ft. wide, and 5 ft. 6 in. deep. The large settling tanks are divided across into sections. In the first sections the grosser solid matters settle at once to the bottom, and in the lower sections the sewage loses a further part of the less dense matters, and then flows over the edge in the condition of water, holding in suspension the finer matter, which however is in quantity very considerable. It is then conducted into a series of 16 secondary tanks, each 150 ft. long, 50 ft. wide, and 5 ft. 6 in. deep, where a further settling is effected; and the effluent water from these tanks is discharged, devoid of smell and nearly colourless, into the river Tame. A small portion of the effluent water is

further purified by intermittent downward filtration through land irrigated by it, and the water flowing from the deep drain pipes of this land is clear and tasteless. In the channel between the roughing and finishing tanks it was Messrs. Hawksley's intention to introduce a small quantity of the crude acid-sulphate of alumina, for the purpose of fixing the remaining ammonia, of mordanting itself with any residual colouring matter, and of producing a further precipitate in addition to the deposition of the finer matters which have escaped from the roughing tanks. It has been ascertained that by this addition a pellucid effluent may be obtained; but it has not as yet seemed necessary to have recourse to this refinement, inasmuch as the existing effluent is in a better condition than is the water of the river Tame, into which it is discharged.

The bulk of the sewage sludge deposited in the tanks, amounting to from 350 to 400 tons per day, is disposed of by double-digging into the land, the extent of land thus treated being such that it takes three years to dig over the whole. A small amount however is dealt with by General Scott's process for producing Roman cement. A portion of the sludge from the tanks is also being experimentally dealt with by concentrating it in Fryer and Alliott's mechanical subsider, which separates the solid matter by centrifugal force, causing it to accumulate round the sides of a rapidly revolving vessel, while the liquid portion drains off; the sludge consists originally of about 90 per cent. of water with only about 10 per cent. of solid matter, and by this treatment it is sought to remove 70 or 80 per cent. of the water, so as leave the solid matter in a condition resembling plastic clay, in which state it can be sold as manure. Mechanical works for pumping and otherwise dealing with the sludge are about to be erected.

The rye grass grown on the farm averages 13 to 14 tons per acre at each cutting, and several cuttings are obtained each year. After each cutting, the land is immediately irrigated thoroughly with sewage; and in about three weeks the next crop is generally ready for cutting.

A number of Works in the neighbourhood were also opened to the visit of the Members.

OPEN SPRAY TUYERE.

Plate 53.

Ordinary Blast-Furnace Tuyeres.

Fig. 1. *Coiled in Cast-Iron.*

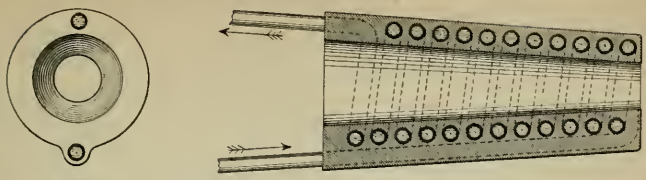


Fig. 2. *Coiled.*

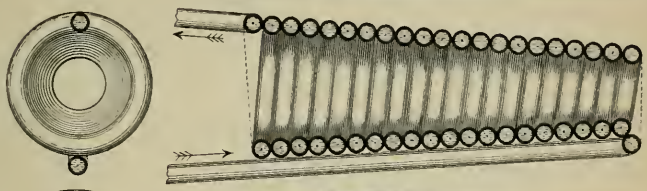


Fig. 3. *Wrought Iron.*

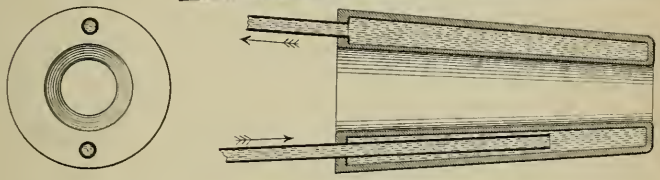


Fig. 4. *Gunmetal.*

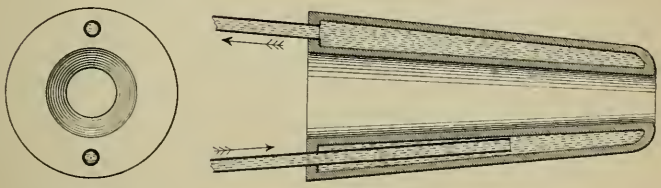


Fig. 5. *Wrought Copper.*

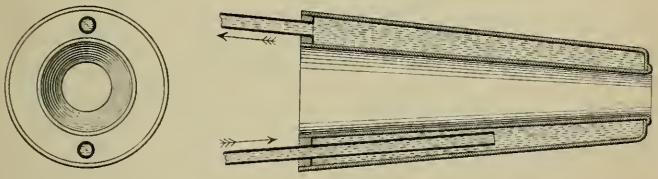


Fig. 6. *Phosphor Bronze.*

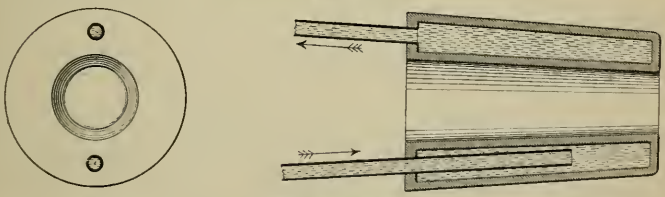
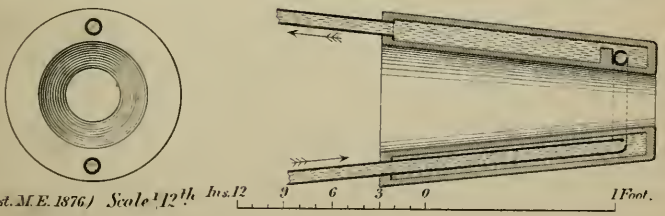


Fig. 7. *Hodgett's.*



(*Proceedings Inst. M.E. 1876.*) *Scale 1/12th* Ins. 12 9 6 3 0 1 Foot.

OPEN SPRAY TUYERE.

General Arrangement of Open Spray Tuyere.

Fig. 8. *Outside Elevation.*

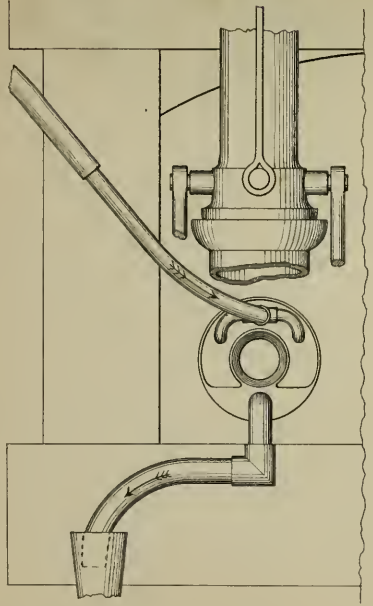
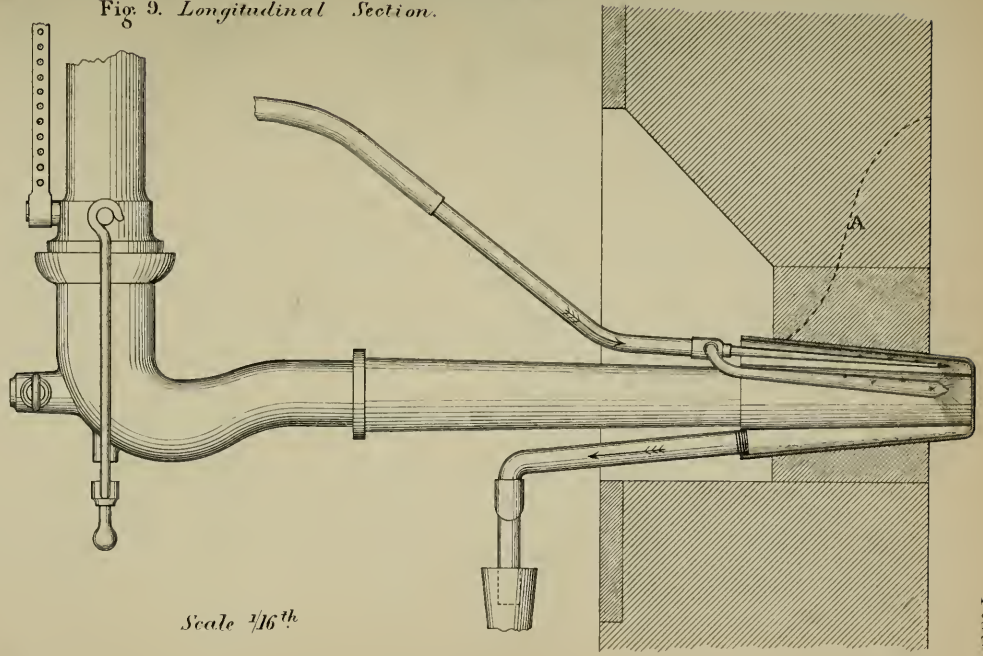


Fig. 9. *Longitudinal Section.*



Scale 1/16th

(Proceedings Inst. M. E. 1876.)

Plate 54.

OPEN SPRAY TUYERE.

Wrought-Iron Spray Tuyere of standard dimensions.

Fig. 10. *Elevation.*

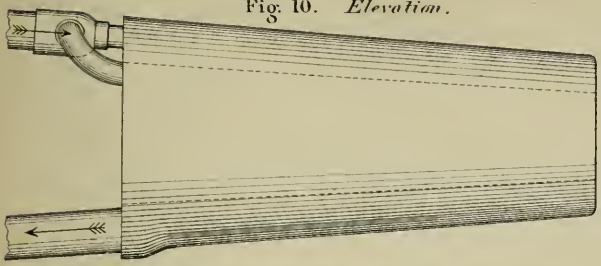


Fig. 11.

Fig. 12.

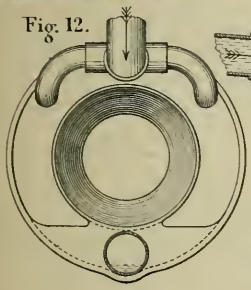
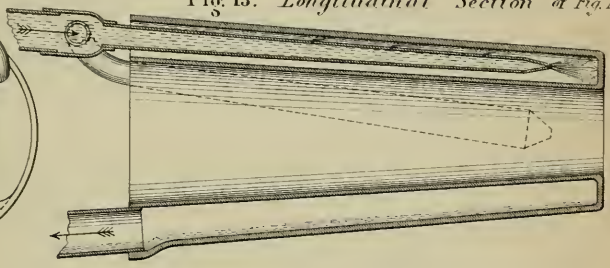


Fig. 13. *Longitudinal Section of Fig. 10.*



Gunmetal Spray Tuyere.

Fig. 14.

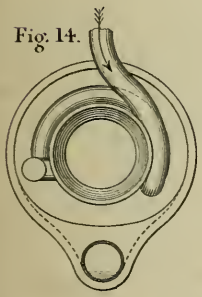
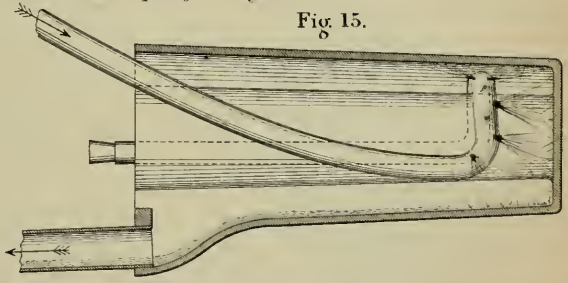


Fig. 15.



Wrought-Iron Spray Tuyere with Brass or Copper Pipes.

Fig. 16.

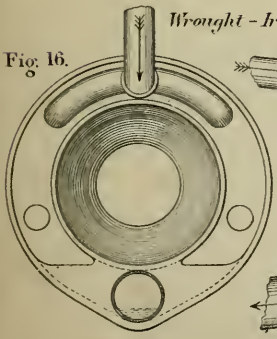
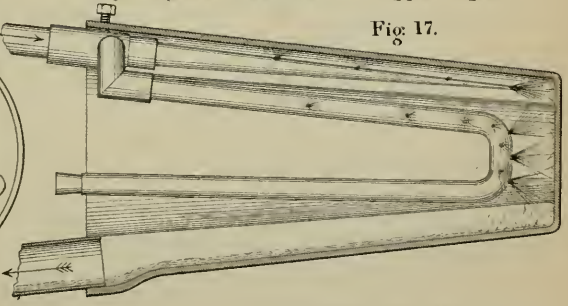


Fig. 17.



(Proceedings Inst. M. E. 1876.)

Scale 1/8th Ins. 12 9 6 3 0 1 Foot.

Wrought-Iron Spray Tuyere with Wrought-Iron Pipes.

Fig 18.

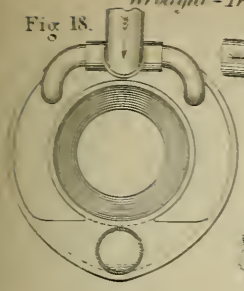
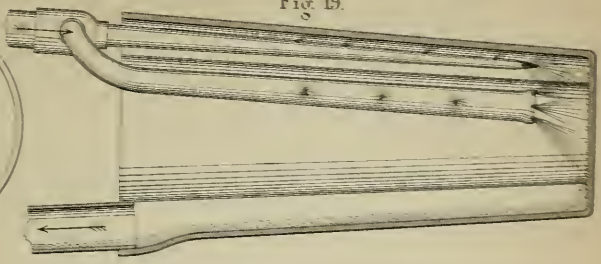


Fig 19.



Wrought-Iron Spray Tuyere with Copper Pipes.

Fig 20.

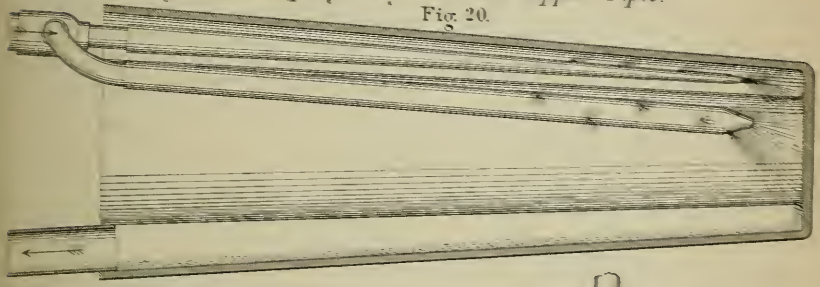


Fig 21. End View of Fig. 20.

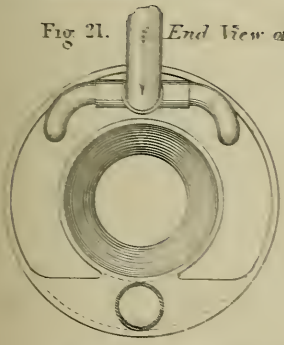
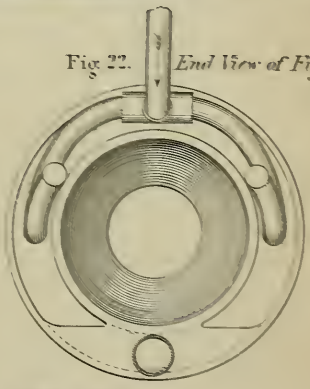
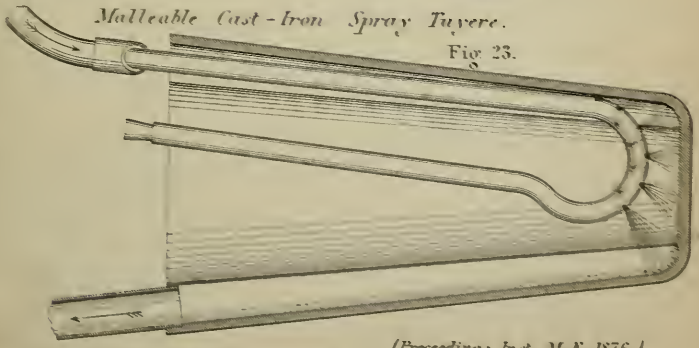


Fig 22. End View of Fig. 23.



Malleable Cast-Iron Spray Tuyere.

Fig 23.



(Proceedings Inst. M. E. 1876.)

Scale 1/8th Ins. 12 9 6 3 0 1 Foot

ROPE GEARING.

Jute Factory, Dundee.

Fig. 3.

Section of Rope Grooves.

Fig. 1.

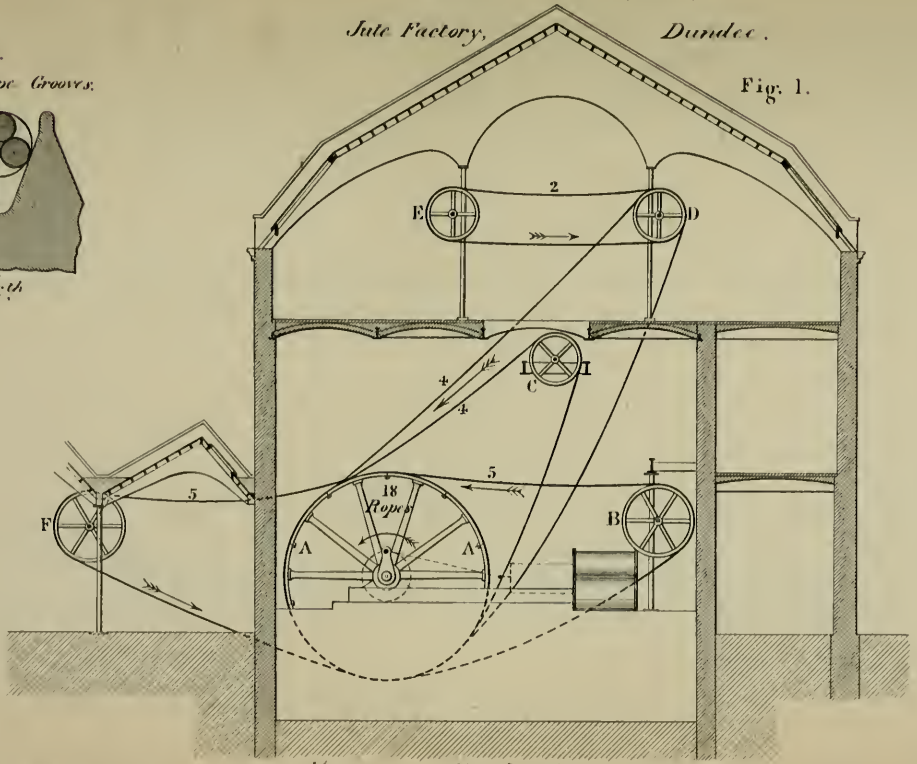
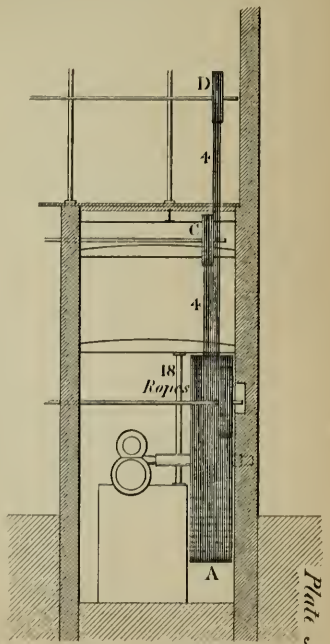


Fig. 2.



(*Proceedings Inst. M. E. 1876.*)

Scale 1/240th.

10 5 0 10 20 30 40 50 60 Feet.

Plate 57.

ROPE GEARING.

Samnuggur Jute Factory, Calcutta.

Fig. 4. *Elevation.*

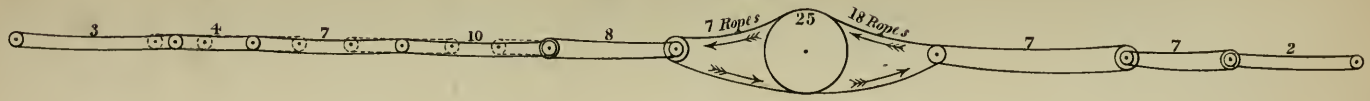


Fig. 5. *Plan.*

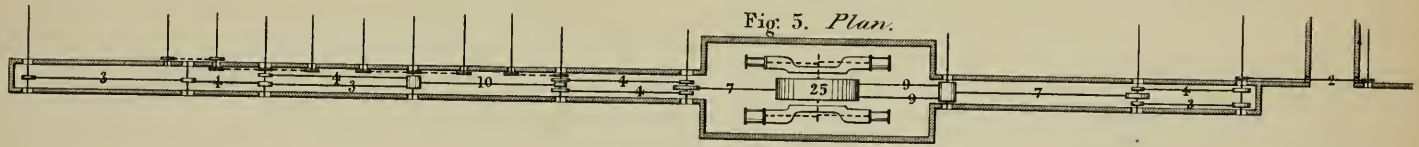
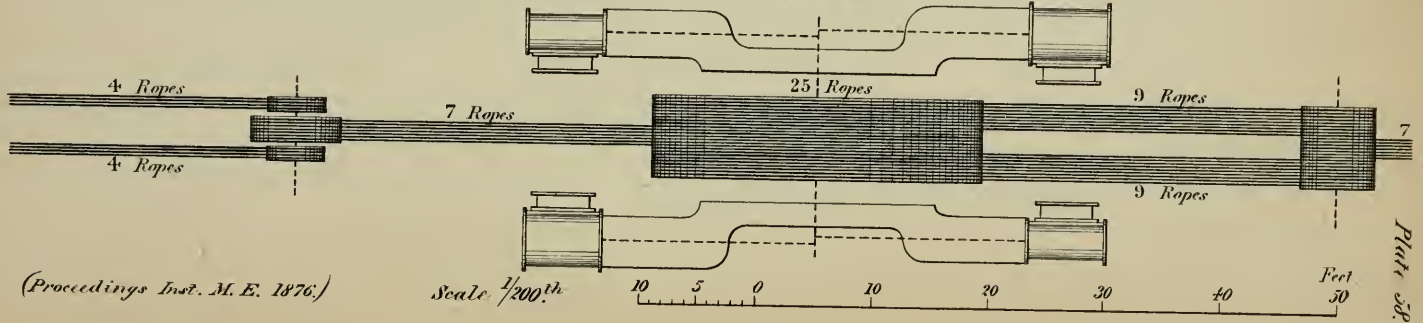


Fig. 6. *Plan of Engines and Driving Drum.*



(*Proceedings Inst. M. E. 1876.*)

Howrah Jute Mill, Calcutta.

Fig. 7. *Plan.*

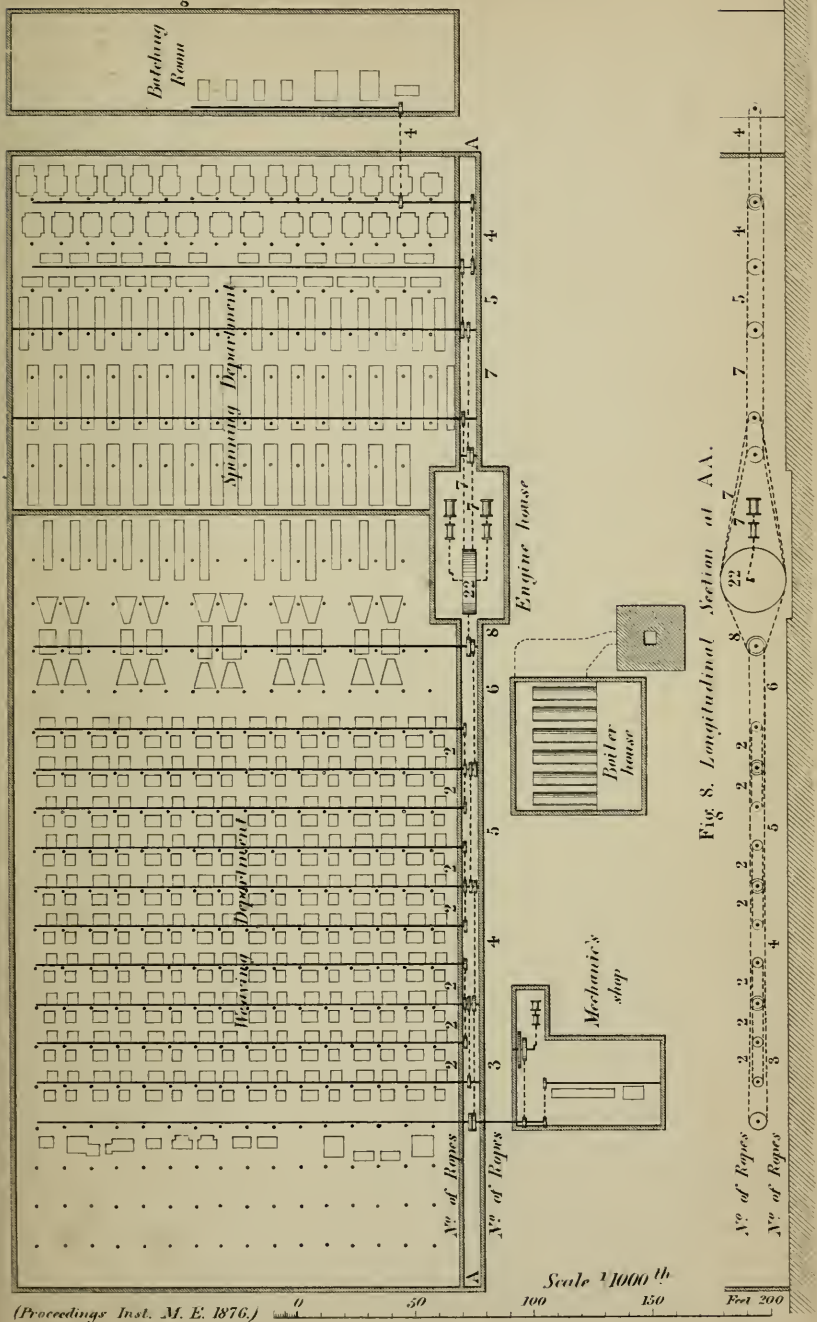


Fig. 8. *Longitudinal Section at A.A.*

(Proceedings Inst. M. E. 1876.)

Budge Budge Jute Mill, Calcutta.

Fig 9. *Plan.*

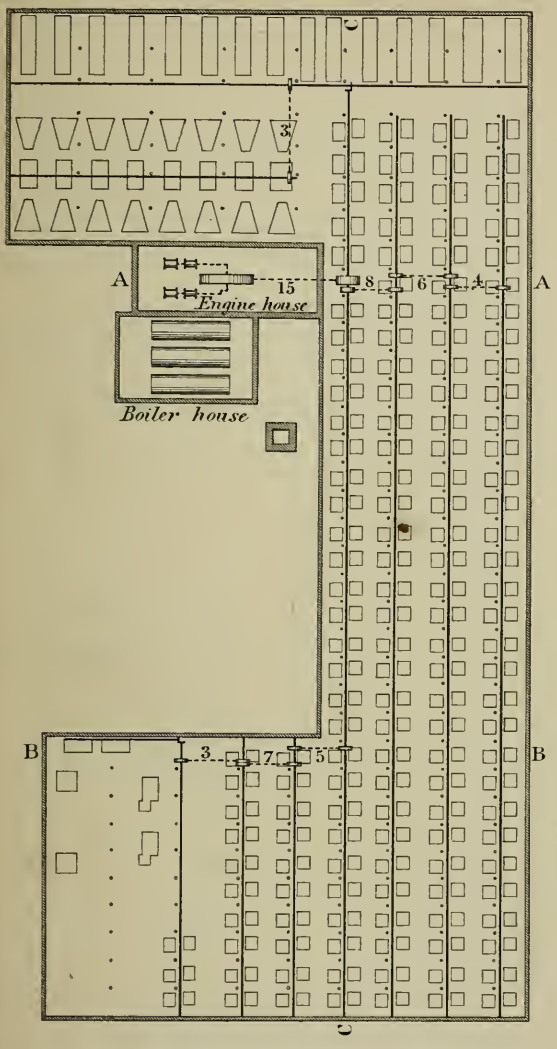


Fig 10. *Transverse Section at* AA.

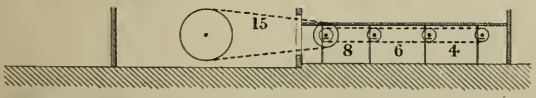
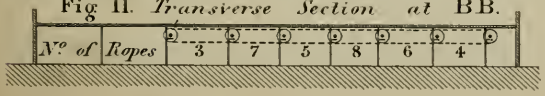


Fig 11. *Transverse Section at* BB.



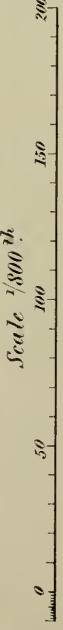
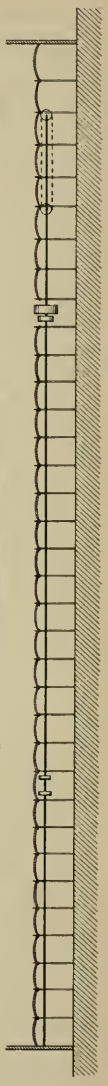


Fig 12. *Longitudinal Section at* CC.



(*Proceedings Inst. M. E. 1876.*)

PROCEEDINGS.

October 1876.

The Autumn Meeting of the Members was held in the Memorial Hall, Albert Square, Manchester, on Wednesday, 25th October, 1876; Thomas Hawksley, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

Charles James Allport,	Sheffield.
Stephen William Challen,	Birmingham.
Thomas Joseph Dawson,	Fence Houses.
Ralph Darling Grundy,	Wigan.
Thomas Heppell,	Chester-le-Street.
Henry James Jackson,	London.
Thomas Lishman,	Fence Houses.
Richard Muirhead,	Chatham.
William Manfield Newton,	London.
Henry James Taylor Piercy,	Birmingham.
Henry Pooley, Jun.,	Liverpool.
James William Restler,	London.
Henry Shield,	Liverpool.
Thomas Ferdinand Walker,	Birmingham.
William Meese Ward,	Tipton.
Thomas Wood,	Fence Houses.

GRADUATE.

George Charles Mickleburgh Owen,	Manchester.

The President announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting in January next.

The following Members were nominated by the Meeting for the election at the Anniversary Meeting :—

PRESIDENT.

Thomas Hawksley, ... London.

VICE-PRESIDENTS.

(*Six of the number to be elected.*)

I. Lowthian Bell, M.P., F.R.S., . . Middlesbrough.
E. Hamer Carbutt, ... Bradford.
Jeremiah Head, ... Middlesbrough.
John Hick, M.P., ... Bolton.
Henry H. Laird, ... Birkenhead.
Walter May, ... Birmingham.
William Menelaus, ... Dowlais.
John Robinson, ... Manchester.
Charles P. Stewart, ... London.
Francis W. Webb, ... Crewe.
Percy G. B. Westmacott, ... Newcastle-on-Tyne.

COUNCIL.

(*Five of the number to be elected.*)

Charles E. Amos, ... London.
Anthony Bower, ... Liverpool.
William Clay, ... Birkenhead.
Charles Cochrane, ... Stourbridge.
Edward A. Cowper, ... London.
Edward Easton, ... London.
Thomas R. Hetherington, ... Manchester.
Edward B. Marten, ... Stourbridge.
John Penn, Jun., ... London.
William Richardson, ... Oldham.
Henry Sharp, ... Bolton.

A notice was given by Mr. C. Cochrane to move at the next Anniversary Meeting the following resolution :—

That the business and house of the Institution be removed to London.

A notice was given by Mr. A. Paget to move at the next Anniversary Meeting the following resolutions for alteration of the Rules and Bye-laws :—

To enable the Council to increase the number of meetings.

The chair to be taken at such hour as the Council may direct from time to time. (Bye-law 1, part 1.)

Each member to have the privilege of introducing one friend to any of the meetings, except during such portions of any meeting as may be devoted to any business connected with the management of the Institution, when visitors shall be requested by the President to withdraw if any member wishes this to be done. (Bye-law 2.)

Communications approved by the Council to be read by the Secretary or the writer of the paper if he prefers to do so. (Bye-law 1, part 4.)

To change the method of enabling the members to correct the reports of discussions in the "proceedings."

To change the practice with regard to making the large-scale drawings for the papers read at the meetings.

The following paper was then read :—

ON THE OPEN SPRAY TUYERE AND OTHER BLAST-FURNACE TUYERES.

By Mr. FRANCIS H. LLOYD, of Wednesbury.

The practice of blast-furnace engineers and managers, as to the dimensions and shape of the Tuyeres they adopt, varies greatly in different districts; but until recently all the tuyeres in use, since the introduction of hot blast first necessitated a water tuyere, may be classed under two heads, namely the coiled tuyere and the water-jacketed tuyere. Various tuyeres on both systems will be briefly noticed, but the principal object of this paper is to describe the Open Spray Tuyere invented by the writer, for which important advantages over either of the systems previously in use are claimed.

The coiled tuyere is generally made of a coil of wrought-iron tube embedded in the sides of a hollow cone of cast iron, as shown in section in Fig. 1, Plate 53. Sometimes the coils are wound close at the nose of the tuyere, in order more effectually to prevent the cast iron from burning; and sometimes the tuyere itself is formed entirely of a coil of tube, closely wound from end to end. This form of tuyere is illustrated in Fig. 2, showing the coil in section.

The water-jacketed tuyere is generally made of wrought iron, and consists of two conical tubes of different diameter, connected at each end by rings of wrought iron welded in, so forming a space between the two concentric walls of the tuyere, which is filled with water supplied under pressure and generally brought in through a feed pipe at or near the bottom of the tuyere, and allowed to escape through a second pipe in the upper side. Tuyeres of this description are illustrated in Figs. 3, 4, 5, and 6; Fig. 3 illustrating the ordinary wrought-iron tuyere, and Fig. 4 the gunmetal tuyere, on the use of which a paper was read before this Institution in 1865 by Mr. Solly, who first introduced tuyeres of this description.

Fig. 5 illustrates a water-jacketed tuyere of a kind which is very much used on the Continent; it is made of wrought copper, the inner tube being brazed in, and a wrought-iron ring either brazed or riveted in at the rear end.

Fig. 6 illustrates the phosphor-bronze tuyere. These tuyeres are generally fixed in a cast-iron casing or box, beyond which they project into the furnace for the greater part of their length, and they are so arranged that they can be turned round in the cast-iron plate or box in order to expose a different side of the tuyere to the action of the materials in the furnace. Greater durability is claimed for phosphor-bronze than for gunmetal or copper, but each metal possesses the same advantage of preventing adherence of slag, scoria, or iron to the nozzle of the tuyere, which is the only object to be gained by the use of copper or its alloys in preference to iron. Additional precautions as to water supply have to be taken where such metal is used, as, owing to the low temperature at which it melts, a tuyere may be more rapidly destroyed than an iron tuyere where any overheating is possible; but under favourable conditions gunmetal, copper, and phosphor-bronze tuyeres have all been found very durable, and the advantage gained by keeping the blast nozzle always clean and fully open is an important one.

Fig. 7 shows a modification of the wrought-iron water-jacketed tuyere, introduced by Mr. Hodgetts, in which the supply pipe is made to deliver its water round the nose of the tuyere through a series of perforations, and the return water is made to flow round the tuyere casing by a fillet placed on the inner tube, as shown in the drawing. This tuyere, like the ordinary water-jacketed tuyere, is close at the back, and is kept full of water.

The Open Spray Tuyere invented by the writer of this paper is shown in Fig. 9, Plate 54, with the blast pipe connected; in the end view, Fig. 8, the blast pipe is broken off so as to show the tuyere more plainly.

This tuyere consists of two concentric conical tubes, closed at the nozzle but open at the rear end. The water supply is connected in the usual manner with a flexible hose, and various systems of spray

pipes are used to suit various shapes of tuyeres and various conditions of water supply. Figs. 18 to 21, Plate 56, represent wrought-iron tuyeres on this system; Figs. 22 and 23 an open spray tuyere of malleable cast iron; Figs. 14 and 15, Plate 55, a small gunmetal open spray tuyere. Figs. 10 to 13 illustrate the open spray tuyere of standard dimensions, showing also a complete section of the tuyere in Fig. 13.

Figs. 16 and 17 show a wrought-iron tuyere with an improved gunmetal or brass fitting, and with brass or copper spray pipes. Although iron spray pipes are now extensively used, and no fault has been found with them, they are liable to rapid corrosion; and the use of brass or copper pipes is found to be an improvement, whilst the additional cost is very trifling. The drawing illustrates the action of the spray, and is shown partly in section for this purpose. A set-pin may be used, as shown, to prevent the spray pipes being accidentally displaced. It has been found advantageous to turn the nozzle of the tuyeres in some cases; by this means the adherence of scoria, or what is commonly known as "ironing," is to a great extent prevented, and the tuyeres are thereby rendered more durable.

The form of spray pipe shown in the illustrations, Figs. 10 to 13, and 18 to 21, consists of three tubes slightly flattened towards the point, and in some cases shaped or bent to suit the shape of the tuyere. These three tubes are joined by a wrought-iron fitting, which is connected by a fourth tube with the water supply. The spray pipes are made either of wrought iron, brass, or copper, and a sufficient amount of water is allowed to escape through small holes or slits in the pipes to protect every part of the tuyere casing which is exposed to the heat of the furnace. In Fig. 23 the spray pipe is shown with the two side pipes bent back and plugged at the ends with wooden plugs, which may be removed occasionally if it is thought desirable to clear the spray pipe from any sediment. The spray or jet of water from each hole in the spray pipe spreads over a considerable surface, and a small number of holes is, if they are properly placed, sufficient to keep the whole interior surface of the tuyere casing constantly wet. Scarcely any steam is visible, and

the waste water passes away, after cooling the tuyere, at a temperature little exceeding that at which it entered, unless a large portion of the tuyere is exposed to violent heat, in which case the temperature of the waste water is certainly no greater than it would be from a tuyere of the old system placed under the same conditions. The spray is principally directed to the nose end of the tuyere and beats back to some extent on the top and sides, which are also protected by a sufficient number of additional sprays from holes drilled in the pipes. The water falls round the sides and end of the tuyere, and escapes from the back at the bottom through the waste water pipe, as shown in the drawing.

The same amount of water which is used in water-jacketed or coiled tuyeres is found amply sufficient to protect spray tuyeres, and it is only in exceptional cases that it is found desirable to use more water than would be required by other tuyeres. It is possible to protect the tuyere by this system with less water than is required to protect a coiled or close water tuyere; but in most cases where these tuyeres have been adopted no change whatever has been made in the connections regulating the amount of water supply.

In cases where tuyeres on the old system are durable, these spray tuyeres are found to be equally so under the same conditions; but where tuyeres on the old system have been giving considerable trouble and lasting only a few days, or at the most weeks, the spray tuyeres have in many instances proved far more durable than those previously used. In some cases where tuyeres required renewal almost every week when coils were used, spray tuyeres have lasted many months.

The durability however of these tuyeres, though now sufficiently proved, is not their main advantage. Like all others, any derangement or choking of the water supply will cause them to burn out; and in common with all other tuyeres they are liable to some of the accidents which will be referred to. It is under such unfavourable circumstances that the advantages of these tuyeres are most apparent. If a small hole be made in the side or end of the tuyere, either from "drilling" or stoppage of water supply, or any other cause, it is still impossible for water to escape into the furnace.

Frequently a tuyere that is heating may be saved by shaking or adjusting the spray pipe; but even if the end of the tuyere is entirely burnt, it is still impossible for water to flow into the furnace, as the blast will at once escape through any aperture, be it small or large, and consequently blow back any spray through the open end of the tuyere casing. If the hole is small and the damage is detected in time, the adjustment of the spray pipe will often cause it to iron up. If too large for this, there is still no necessity for haste in removing the tuyere, as the escape of blast through the aperture drives back the spray and prevents the possibility of any harm or danger, such as would result from the fall of this water into the furnace.

When a spray tuyere is damaged, it can generally be repaired after removal by welding a small piece of iron on the damaged part; or in the case of gunmetal or copper tuyeres, a piece may be tapped or brazed in and the tuyere made as good as new, at a very trifling expense.

The principal causes of injury to water tuyeres of all kinds may be enumerated as follows:—

1.—The stoppage of supply pipes through incrustation, or from the deposit of mud, shells, dirt, or vegetable matter accumulating in the tank or reservoir from which the water supply for the tuyeres is obtained.

2.—"Drilling," caused by the constant dropping of metal or slag on an exposed part of the tuyere, which in the course of time forms a hole in the surface exposed to it. Where a defect arises from this cause, it will be found in the upper side of the tuyere. "Drilling" is also caused by molten metal or slag attacking the nozzle and the lower surface of the tuyere; this may arise from the defective working of a furnace, where the contents of one side of the hearth have become partially solidified, and there is no regular fall or "sink" of materials. In this case the molten metal or slag being unable to get away, the action of the blast may cause it to beat back against the nose or lower surface of the tuyere until the continued action drills or burns a hole in the tuyere.

3.—A third cause of destruction to tuyeres, which is more readily capable of explanation, arises when the materials in the furnace are so dense as to prevent the blast ascending freely, causing it to fight round the tuyeres, destroying the stopping, and leaving the greater part of the tuyere naked and exposed to heat as shown by the dotted line at A in Fig. 9, which under such circumstances is unusually intense round the tuyeres. A close tuyere, fed in the usual manner, when exposed to excessive heat, will sometimes refuse its full supply of water, either from the generation of steam in the tuyere, or from some other cause, and this may cause the tuyere to burn, and thus allow the escape of water into the furnace.

4.—Slips of material after a furnace has been hanging will sometimes destroy or blind every tuyere in a furnace, by the fall of solid material on them or in front of them. Accidents to tuyeres from this cause have not unfrequently caused severe explosions.

5.—Another cause of injury to tuyeres, and of great danger where close tuyeres are used, arises from the slag, or in some cases the molten metal, rising up to the tuyere level. This may happen from neglect of the workman to open his furnace in time, or from having a hard tap so as to delay the running of the molten metal at casting time. In all cases it is when damage to close water tuyeres has been occasioned by the rising of metal or slag to the tuyere level that the greatest danger from the escape of any water into the furnace is to be feared.

The leakage from a very small hole in a coil or close water tuyere, from whatever cause it arises, will in most cases be evaporated by the heat of the furnace, and cause no further damage than a trifling loss of heat; but the same action that causes a small defect will very often increase the aperture before any leakage can be detected, and when leakage occurs from the lower side of a tuyere, it is not unfrequently difficult to detect by examining the blast opening in the usual manner. An instance of this has been brought under the notice of the writer, in which a coiled tuyere leaked, but owing to the position of the defect no indications of leakage were found on examination of the tuyeres, all the tuyere openings showing a

perfectly bright and clear fire. After a time the furnace manager became convinced from other indications that leakage was going on. He caused every tuyere to be removed, and the materials below a tuyere on one side of the furnace were found to be literally soaking with water, and had to be raked out to a considerable depth before fire could be found. What would have been the consequence if this mass of wet material had been forced into the molten iron below is well illustrated by an explosion that occurred during the present month at some furnaces in Lancashire, resulting in the death of seven persons. It appears from the evidence at the inquest, that this explosion was occasioned by a slip in the furnace destroying one or more tuyeres, and it was suggested that it arose from damp material caused by previous leakage of the tuyere being suddenly forced into the hot metal.

Accidents of a very serious nature have occurred from the use of water-jacketed tuyeres in the Staffordshire district. In September last year an explosion occurred resulting in the death of four men, and in the following month the explosion of a water tuyere caused very severe injuries to fifteen men, of whom eight died either on the spot or within a short time afterwards. In the latter case the severity of the explosion was occasioned by the iron having been allowed to rise to the tuyere level through the carelessness of the keeper in charge of the furnace. The tuyere which caused this explosion was produced at the inquest, and showed a small hole, about half an inch in diameter, on the outer edge of the nozzle. This circumstance makes it seem probable that a similar result would have occurred if a coiled tuyere had been in use instead of a water-jacketed tuyere.

Besides these fatal accidents, two others causing considerable damage to property, though fortunately not resulting in loss of life, have since been reported, both of them arising from the explosion of water-jacketed tuyeres.

A simple and ingenious arrangement has been introduced by Mr. Thomson of Ruabon for the purpose of detecting leakage when it occurs from any close tuyere. It consists of a water balance, which, so long as the same amount of water flows from

the tuyere as is supplied to it, is kept in equilibrium; but the moment any leakage occurs, the equilibrium is disturbed, and by this means a whistle or alarm is sounded. This arrangement is said to answer well, and to give warning when a very slight amount of leakage occurs. The warning however, even if promptly acted upon, would not in all cases prevent danger, as in the case of the destruction of a tuyere from a sudden slip in the furnace.

The danger of accident from the causes alluded to is effectually prevented by the use of open spray tuyeres.

Where incrustation is a cause of difficulty with other tuyeres, this system provides a complete remedy. The incrustation, as it forms, can be seen from the open end of the tuyere casing; and it is only necessary to stop the water supply for a few seconds, or for a sufficient time to dry and slightly heat the tuyere, causing the incrustation to crack and fall off as soon as the water is again turned on. If it is but slight, the incrustation will very soon be washed away; but if hard and thick, a repetition of the process once or twice will almost invariably remove it without damage to the tuyere.

Stoppage of the spray pipes from incrustation, mud, or other impurities may occur, but is not more liable to do so than in the water connections of other tuyeres, and in most cases the sediment escapes through the spray holes without any danger of choking them. With vegetable fibre or any large obstruction of course this cannot happen, and stoppage from these causes may result in the burning of a tuyere; but owing to the end being open, any such stoppage can be very readily seen, and may very often be remedied before any damage occurs.

If an open spray tuyere drills, the blast at once escaping through the aperture prevents any water from entering the furnace, and thus avoids the dangers, inconveniences, and loss of heat resulting from leakage where other tuyeres are used. Damage to the open spray tuyere arising from any other cause is equally free from danger, owing to the fact that no body of water is allowed to remain in the tuyere, and that the spray is at once blown back

through the open end in the event of any aperture being made through which the blast can escape. Another advantage of considerable importance arises from its being unnecessary hastily to remove any tuyere or stop the water supply where this system is adopted, as a tuyere if damaged from any cause may be kept in use without danger and generally without inconvenience until an opportunity occurs for stopping the blast and replacing it.

Spray tuyeres have been made of wrought iron, ordinary cast iron, malleable cast iron, gunmetal, and phosphor-bronze; also of wrought iron with a nozzle of other metal. Open spray tuyeres are now in use at about one half of the furnaces in blast in South Staffordshire, and are being adopted also in other districts. The sizes already supplied vary in length from 10 in. to 3 ft., and in diameter from $2\frac{1}{2}$ to $6\frac{1}{2}$ in. at the nozzle. No difficulty is found in adapting the system to tuyeres of any size or shape.

The tuyere shown, $3\frac{1}{2}$ in. diameter at the nozzle, and 20 in. long, is similar to a large number now in use, and is about the size generally used in the Staffordshire district.

The 3 ft. tuyere, 5 in. diameter at the nozzle, is that now adopted at the West Cumberland Iron Co.'s furnaces.

The 6 in. tuyere is the size supplied to some furnaces in the Cleveland district.

The 4 in. tuyere of malleable cast iron is of the dimensions used by a firm in Lincolnshire.

The perfect safety of these tuyeres is admitted by every one who has tried them, and in most cases they have been found more durable than tuyeres on the systems previously in use, whilst at the same time the saving in actual cost over a few months, as compared with other tuyeres, has not been inconsiderable.

Mr. Lloyd exhibited a number of specimens of the open spray tuyeres of different sizes and make; and also one of wrought iron which had been in use three months in a blast furnace at Messrs. Cochrane's Woodside Iron Works near Dudley, and had been removed in consequence of becoming "drilled," having two holes burnt in the nose; but it had been kept at work without danger for some hours after the burning of the holes, as the blast escaping through the holes blew back the spray of water and prevented any water entering the furnace.

Mr. C. Cochrane thought the Institution, and ironmasters generally, were much indebted to the author of the paper for having introduced a tuyere which would remove those sources of danger that in past years had been so serious to blast furnaces. He believed a great misconception arose in the minds of the public, and very strongly perhaps in the minds of coroners' juries, as to the cause of blast-furnace explosions. There were two distinct classes of explosions, as shown in the paper—those that took place within the furnace, due to the leakage of water into the furnace—and explosions of the tuyere itself, by which external damage was done in the tuyere house. The old wrought-iron jacketed tuyere had been in common use in Staffordshire twenty years ago, and his own first experience in connection with the subject had been with that class of tuyeres. One source of danger with those tuyeres, or, if not a source of danger, at any rate a source of considerable loss in working, which had not been alluded to in the paper, consisted in the difficulty of making a perfect weld in the tuyere case, so that no water should escape into the furnace; a slight leakage of water would cause material loss in fuel by delivering steam with the blast into the furnace. It had been quite a common thing to have to take out one of those jacketed tuyeres because of a failure in the weld; and the difficulty was obvious of making a weld of that character, where there were two surfaces to be welded so near together that it was difficult to make both welds secure. Any similar imperfection in the welding of the spray tuyere would be attended with no such inconvenience. A simple mode of detecting leakage that was in

common use—if the water did not show itself by running over the forepart of the furnace, running out over the molten slag in a spheroidal condition so that it would not come in contact with the slag—was to take the blast off the furnace for a moment or two, and thrust a cold iron bar through the tuyere into the furnace, withdrawing it again instantly. If the tuyere was leaking, in nine cases out of ten moisture would be condensed upon the bar; and the tuyere could then be immediately removed. After the experience of South Staffordshire, when the blast furnaces commenced in Middlesbrough the coiled tuyere was most frequently adopted, and it took the form at last of a continuous coil, like that shown in Fig. 2. It was obvious that the piercing or "drilling," as it was called, of a water-jacketed tuyere might permit the melted iron absolutely to pass through the water, leaving it in a spheroidal condition, the iron lying in a body at the bottom of the tuyere; and that in this way the tuyere might positively become a steam gun ready to blow up at the moment when the water came in contact with the melted iron, that is, the moment the iron had cooled down sufficiently to allow the water to come in contact with it; and the danger with that construction of tuyere arose from the large reservoir of water that there was to be acted upon and to be converted into steam. Such an effect could not be produced with a coiled tuyere, because there was only a limited space for the iron to accumulate in, so that any explosion that might take place would be only of a trifling character; at any rate there would be no such serious explosions as had been recorded where the jacketed tuyere had exploded. But, as mentioned in the paper, there was another accident to which a coiled tuyere was as liable as a water-jacketed tuyere, namely the creeping up of the melted iron in the furnace to the underside of the tuyere, so as to burn a hole in below; then the water poured into the furnace, and produced those disastrous explosions, which were commonly called explosions of the blast furnace, but which were really explosions of water coming into contact with a large surface of melted slag or iron in the furnace; the whole of the material in the furnace acting as a breech to a gun, the pressure of the steam blew out the liquid slag and iron, and burnt to death or scorched severely any one who

might be in its path. That was one of the most alarming explosions that blast furnaces were liable to.

One point to which attention had to be drawn was that the coiled tuyere was not used in the way shown in the drawing; when the blast had been heated to the highest temperature desired, it was not wished to have it cooled again, and there was no cooling action greater than that of the surface of a coiled tuyere like the one shown in Fig. 2, or even of the open spray tuyere where there was no internal jacket or lining to convey the blast so that it should not impinge against the internal surface that was kept cool by the spray, this surface being equally cool with that in the water-jacketed tuyere. It was important not to cool the blast after it had been raised at such an expense to the temperature desired, and that difficulty had been got over with the coiled tuyere by plastering clay all round the inside of the coil, and then driving in a conical iron pipe as a lining, which was thus removed from the cooling action of the coil, and enabled the blast to be delivered into the furnace with only a very slight loss of temperature in transit through the tuyere.

With regard to the means of getting rid of the annoyance caused by the stoppage of the apertures in the nozzles of the spray pipes in the open spray tuyere, the first application of this tuyere at the Woodside Iron Works had been attended with so much trouble from this cause that the nose of the tuyere had absolutely become eaten through in two places, as seen in the tuyere itself now exhibited, owing to the partial failure of the supply of water. This was an illustration of the extreme risk which would be incurred of the water running into the furnace, if the blast did not literally blow the spray back again, and refuse to permit it to enter the furnace. He had got over the difficulty by putting into the tank which supplied the tuyeres a frame with double sides, each containing a copper gauze, the meshes of which were about 64 per inch, making the apertures of the meshes very slightly smaller than the holes delivering the spray of water to the tuyere. By that simple expedient any difficulties from stoppage of the spray nozzles were effectually prevented, and the tuyeres were now doing remarkably

well; previously there had been the annoyance of little fish and shells coming down into the nozzles with the water, but that was now completely stopped by this means.

Mr. D. Adamson had great pleasure in confirming the good opinion which had been expressed by Mr. Cochrane respecting the open spray tuyere. Having himself been one of those who had suffered loss from explosions of the ordinary cistern or coiled-pipe tuyere, he felt persuaded that every one, who was acquainted with the disasters that arose when a large quantity of water was projected into a blast furnace, would be of the same opinion with regard to the open spray tuyere now described; it appeared to him to be a very desirable and excellent invention. The ordinary cistern tuyere was he considered the worst of all, inasmuch as it carried in itself such a large body of water; and if the hot metal as it was passing down the furnace in its melted state lay on the top of the nose of the tuyere, and burnt through it, the large quantity of water contained in the tuyere being thrown into the furnace, a disastrous explosion might instantly arise. He questioned however whether the condition of circumstances had been stated in the way in which it really occurred; an explosion did not arise quite from the water being projected upon the melted metal, as it was a very common thing for tuyeres to fail and for water to be projected into a blast furnace, and yet no explosion at all occurred, and under these circumstances it must necessarily happen that the water did not go below the metal. But should it happen that some piece of material on the nose of the tuyere that was saturated with water broke off or was melted off, and dropped down into the metal itself, then he apprehended an explosion of greater or less intensity took place instantly. In an explosion that had happened to one of his own blast furnaces at the North Lincolnshire Iron Works, Frodingham, half of the entire mass of melted iron and slag in the hearth was projected out at the forebreast, the charging bell at the furnace top was blown off, and other great disturbances took place by a fresh explosion of the gas, and very serious results were produced in loss both of life and of money.

By the open spray tuyere he thought blast furnaces would be largely protected from many of these liabilities and disastrous consequences.

There was one thing connected with the open spray tuyere that he thought wanted a little further elucidation. The spray pipes in the tuyere appeared to be perforated somewhat equally throughout the three pipes. Now it occurred to him that when a tuyere was not working properly, should it be getting hot from a disturbed condition of the furnace, or from the metal rising on account of the hearth getting full in consequence of neglect to take off the slag or tapping—all which were conditions that did arise,—and if one particular part of the tuyere should get hot and should be seen by the man in charge, then if one of the three spray pipes could have a greater quantity of water discharged through it than the other two, by adjusting a tap, it appeared to him that this would be better than allowing the whole supply of water to be distributed equally through the three pipes, when one side of the tuyere might be cool and the other very hot.

His own experience in Lincolnshire had been mostly at first with what was commonly called the Scotch tuyere, that is the coiled tuyere with a cast-iron jacket upon it (Fig. 1); and subsequently with a tuyere like that shown in Fig. 2, a mere coiled tuyere lined with fireclay. He was anxious to bear his testimony to the accuracy of the view that had been expressed by Mr. Cochrane, that it was exceedingly desirable that the blast should not be cooled in its passage through the tuyere by striking against the sides of the tuyere itself, and thereby merely boiling the water rather than sending the hot blast into the furnace at its full heat. In all his experience with workmen having the charge of blast-furnace tuyeres he had found there had been a disposition to leave the nose of the blast pipe very short, so that the hot blast striking the water tuyere made it exceedingly hot, endangering the tuyere and putting the furnace in the worst condition by blowing in a cold blast instead of a hot blast. The same principle would apply to the spray tuyere; but in his own experience he had always recommended that the taper of the tuyere should be increased, and that the packing of

fireclay rammed into it round the nose of the blast pipe should be made thicker, while the blast pipe should be brought nearly up to the nose of the tuyere, say within two or three inches of where the blast entered the furnace. By having the tuyere a little larger and using a little more fireclay, not only was the blast protected from being cooled, but the water in the tuyere was kept cooler and the tuyere made to last longer.

There were other conditions in which the open spray tuyere would be advantageous; in a few cases that had come under his experience lately in some blast furnaces on the West coast near Whitehaven, where the water supply for the tuyeres was obtained from Parton Beck, a small brook containing fish, tuyeres had been lost by small eels passing through the supply pipes and getting stuck fast in the coils of the tuyere. If one of the spray pipes in the open spray tuyere became stopped, the attendant would be able to see that a stoppage had taken place, and could have the pipe removed at once and a fresh one supplied. He was quite of opinion that many of the serious explosions that occurred with blast furnaces would be obviated if the spray tuyere were used; and he hoped it would be adopted, both for the sake of human life, and also to avoid the disastrous consequences which arose when a large quantity of water by any means got projected into the interior of a blast furnace.

With regard to leakage, it had been pointed out that in the early period of the leakage it had not always been possible to tell whether the tuyere was leaking or not; but supposing there were a leakage, the working of the furnace was manifestly altered in the early period by a larger quantity of extra gas or steam passing off either from the chimney or from the furnace top itself. He had frequently had an opportunity of observing that the gas increased to such an extent that the keepers were ordered at once to look round the furnace; and thus a leakage had been detected, when from what could be seen at the tuyere itself no leakage had before been apprehended. He merely mentioned this as one of the ways in which the interests both of ironmasters and their workmen might be protected. No doubt the difficulties were increased when the furnace was in

trouble; when a furnace was in good working order, many difficulties did not arise with the tuyeres. He had received recently a report of two blast furnaces that had worked three consecutive months without having changed a single tuyere; on the other hand furnaces had been working under unfavourable conditions, the blast not passing through them in a proper and regular manner, when probably during the same period of working a hundred tuyeres might have been required. Changing the tuyeres stopped the furnace, added to the trouble, and was a serious and costly operation; so that if by any means a tuyere could be obtained that would enable the furnace keeper to see at once when it was out of order, it would be a great saving to every ironmaster and a great comfort and protection to all the workmen.

The President enquired whether it would be possible to substitute a platinum tuyere, and so get rid of the water supply altogether.

Mr. D. Adamson did not think that would be practicable.

Mr. F. W. Webb asked whether the open spray tuyeres had been applied to cupolas. He had been using for some time cupolas with twelve tuyeres, in two tiers, the upper tier being smaller than the six lower ones, in the manner originally proposed by Ireland, melting continuously from Monday morning to Saturday night, so that the bosh or neck of the furnace got pretty large by the end of the week from wearing away; and his only objection to using the water tuyere had been the fear of explosion. If it had not been already introduced for cupola work, he should think the open spray tuyere would come in very well for enabling a still further reduction to be effected in the consumption of coke in remelting iron for the Bessemer process. If it had not yet been tried, he should be glad to give it a trial, and to report the result to the Institution.

Mr. E. A. Cowper congratulated the author of the paper on having contrived what appeared to be a very successful apparatus.

He thought it recommended itself to common sense that, if the surfaces of a tuyere were kept cool by water, and the water were supplied in a space where it could not do harm by explosion, a very safe apparatus would be obtained. He called attention to the fact that only a certain moderate pressure of water should be supplied to the spray pipes, because if too small a pressure of water were applied, there was danger of the surface not being thoroughly wetted; and on the other hand if too great a pressure were applied, instead of doing more good, it would positively do harm, by not keeping the surface so cool as a certain moderate pressure. Under a heavy pressure the water would be splashed against the surface of the tuyere, against which it would dash and be broken into spray, and would thus leave the surface with much less water on it than if a jet were thrown gently against it. He had tried experiments with a number of different surfaces—wood, iron, and other materials—placed at different inclinations. Placing for instance a piece of board or a plate of iron at a slight inclination from the vertical, he had applied a jet of water to the upper face, not at right angles but at a slight inclination, with a head of water of one foot. He had tried many experiments with different heads and different sizes of jets, and had found that a jet of $\frac{1}{4}$ inch diameter with about 1 ft. head of water appeared to give the best result in extent of surface wetted in proportion to the quantity of water used. The most effective pressure was found to be confined within pretty close limits; with a 3 ft. or 4 ft. head the water would dash and splash about, and the full effect would not be obtained, and a larger quantity would be required to do the work; but if much less head were employed, the water scarcely distributed itself over the surface. A jet of 1 ft. head gave a surface of 16 in. width and 3 ft. length entirely covered with water; therefore in the case of vessels or surfaces that were required to be kept cool, a $\frac{1}{4}$ in. jet would suffice with a head of 1 ft., which represented a very small quantity of water. He had also tried experiments to see how far the water had power enough to keep down the temperature of a surface which would naturally become red-hot owing to its being exposed to a fire; and in order to try that thoroughly, he had made a surface

red-hot, applied a jet, and thoroughly cooled it down. A piece of channel iron of about 5 in. width was placed inverted across a smith's fire, not quite horizontally but at a very slight inclination; and a large fire was banked up on it until 2 or 3 ft. length of it was red-hot. Then outside, beyond the hearth, a $\frac{1}{4}$ in. jet was put to play up against the underside of the channeled bar; the wetting widened out to the full width of the bar, and ran right through the red-hot part, and effectually cooled it down until it became perfectly black and afterwards cold, while the temperature of the water itself was only raised a few degrees as it passed along the underside of the bar. This showed that a spray of water properly applied had the power of keeping cool a surface that would become red-hot from a fire acting upon it; that was the only point that there could be any doubt about, and these experiments proved it satisfactorily. He wished every success to the open spray tuyere, which was a great boon to ironmasters and a still greater boon to the blast-furnace keepers.

Mr. Jeremiah Head, referring to the mention that had been made of keeping cupolas working night and day for a week together, said that in the Cleveland district there were two or three cases of cupolas so working; the object was accomplished by placing a water bosh as a belt round that part of the cupola through which the tuyeres went, there being more surface of the water bosh above the tuyeres than below. These were working very successfully, but the consumption of coke was a little more than in the ordinary cupola; they were quite successful in keeping the form of the internal part of the cupola pretty regular for a whole week, working night and day. The quantity of pig iron melted down by each cupola was about 4 tons per hour. The diameter of the cupola at the lower part of the water bosh was about 3 ft., and the height of the belt was about 3 ft. 4 in., the inner surface of the belt being lined with ganister about 3 in. thick; if more than this thickness of ganister was placed round the water belt it would soon melt away, and would continue to do so until the coolness of the water protected the ganister and prevented it from being melted through. The water

belt was made of cast iron, in four segments, which were bolted together round the cupola; occasionally one of these segments was known to crack, and then it was replaced at the end of the week, which could be done easily. The water entered the segments not under pressure, being simply poured in and poured out, and there was no danger of any explosion from generation of steam.

Mr. Lloyd quite agreed with Mr. Cochrane's remarks about explosion in the tuyere itself being very unlikely with coiled tuyeres, and extremely dangerous where the old water-jacketed tuyere was used. From information that he had obtained with regard to explosions that had occurred at blast furnaces, he believed some of the worst of them had happened where water tuyeres had been used, from the "drilling" of the tuyere and the melted metal actually entering the inside of the water space and causing an explosion of the tuyere itself: but equally disastrous explosions had occurred through the leakage of water from the nose of the tuyere upon the material below, inside the furnace; then any sudden fall in the furnace might force this mass of damp material into the melted metal in the furnace. That he believed had been the opinion expressed as to the cause of the recent explosion at a blast furnace in Lancashire.

With regard to the burnt specimen of an open spray tuyere exhibited from the Woodside Iron Works, it would be seen that there was a great difference in form between that and the more recent ones. That tuyere he supposed had been supplied as long as eighteen months ago, and it would be seen that it had a much larger surface exposed to the heat and the wear and tear of the action of the furnace than there was in the form now adopted. The spray pipe belonging to it was partly coiled round the inner tube of the tuyere, like the spray pipe shown in Fig. 15, and in order to get this coil into the conical tuyere it was necessary to make the back end of the tuyere smaller than was now adopted. That resulted in the adoption of the present plan of three straight spray pipes in preference to the coiled shape, simply in order to obviate the difficulty that had been mentioned, which was that if there were

not sufficient taper in the inner cone of the tuyere it was impossible to bring the nozzle of an inner blast pipe close up to the nose of the tuyere. With the form of spray pipes now used, there was no difficulty whatever in protecting tuyeres of the shape required, leaving sufficient room for ramming clay round an inner blast pipe, which might if thought desirable be brought up almost to the very nose of the tuyere, so as to protect the hot blast from any cooling action of the tuyere.

With regard to filtration of the water supplied to the tuyeres, it had been anticipated by some that there would be a difficulty on that score with the spray tuyeres; and he must confess that water containing such impurities as eels, shrimps, and shells, presented a difficulty which might not easily be contended with in the absence of filtration. At several blast furnaces where the open spray tuyeres had been adopted some difficulties of this nature had been experienced. Where open spray tuyeres were used of the large size exhibited, 3 ft. length, they had been employed for many months, notwithstanding the use of salt water in which there were many bits of seaweed or other impurities. Of course that made the tuyeres less durable, and rendered it necessary to remove and examine the spray pipes somewhat oftener; that was the extent of the difficulty. It had since been found desirable to improve the water supply; but for many months, he thought for nearly a year, the ordinary salt water supply had been used.

With regard to the perforations in the spray pipes, it was easy to remove one of the spray pipes in a few minutes, without allowing time for the tuyere to be destroyed; and where a tuyere was found to be working very hot on one side, he thought it might be desirable to have a spare spray pipe with additional water supply. The conditions varied much in different blast furnaces: in some cases the tuyeres were not required to project into the furnace beyond the distance shown in the drawing, Fig. 9; in other cases a much greater part of the tuyere was exposed to the action of the furnace, as when the stopping was worn away as represented by the dotted line at A in Fig. 9, or when the tuyere was purposely made to project 10 or 12 inches into the furnace. Of course it was desirable

under some conditions to use discretion as to how the perforations should be made in the spray pipes, as to their number and size, and whether slits or round holes should be used. To meet certain cases he had recently adopted the form of spray pipes exhibited, flattened towards the ends, with a few perforations in the sides and a slit at the extremity, so that the jets of water issuing from the ends of the pipes did the main work of cooling the nose of the tuyere, while the spray from the side perforations cooled the sides of the tuyere. The narrower the surface was in the interior of the tuyere, the easier it was to protect it from heating; whereas a large tuyere, like the defective one exhibited, was much more difficult to protect, or would take more water to protect it than a smaller one.

The open spray tuyeres had not been applied to cupolas at present, and he was glad to know that they might be adapted to that purpose; the principle had however been applied to other tuyeres besides those of blast furnaces, and he was now making open spray tuyeres for Lancashire hearths in Sweden. It would be easy to adapt them to cupolas as well as to other purposes. The use of these tuyeres he imagined would enable the sides of the cupola to be kept much more regular. In the cupolas that he had been accustomed to use, water tuyeres had seldom if ever been employed; and he had never heard of any explosion or any difficulty arising in the case of cupolas.

Mr. F. W. Webb was not aware that water tuyeres had ever been used for cupolas before; but times were changed, and melting had now to be done continuously. A cupola was wanted to run from one week's end to another, like a blast furnace, without any great change in its internal surfaces; and this was wanted to be done without having a large cooling surface such as was necessarily presented by the use of a water bosh or belt like that which had been mentioned.

Mr. Lloyd believed the open spray tuyere would be an effectual help for cupolas, but the tuyere surface required to be protected would be very small in such cases.

One of the specimens exhibited of the open spray tuyere was of malleable cast-iron, and the object of making it of this material had been rather to prevent the accumulation of scoria upon the nose; and his experience so far went to prove that malleable cast-iron tuyeres if made sufficiently thin were almost as good as brass tuyeres for that purpose; if they were kept sufficiently cool at the nose no scoria would adhere.

Another of the open spray tuyeres exhibited had been taken out after six months' work from a blast furnace where the tuyeres previously used had seldom lasted more than as many weeks, and it was found then as perfect for practical use as when first put in.

With regard to Mr. Cowper's remark respecting the head of water suitable for the supply of the spray tuyeres, this was confirmed by his own experience in one case. There were two blast furnaces belonging to the same firm in different parts of South Staffordshire, at one of which there was a head of 40 ft. for supplying the tuyeres, and at the other only 4 ft., the open spray tuyeres being adopted in both instances. Where there was only 4 ft. head and larger holes in the spray pipes the tuyeres had been found more durable; and it was now desired to have the same water arrangement in the other case.

Mr. E. A. Cowper said that a low pressure might be obtained by having a cock in the supply pipe, so that the pressure could be reduced; it was then of no consequence what the head was, and would depend entirely upon how much the cock was opened.

The President proposed a vote of thanks to Mr. Lloyd for his paper, which was passed.

The following paper was then read:—

ON ROPE GEARING FOR THE TRANSMISSION OF LARGE POWER IN MILLS AND FACTORIES.

By Mr. JAMES DURIE, of Manchester.

The best means of transmitting power from the prime mover to the various machines in a factory has long been a matter of importance to the engineer and to the manufacturer. Until lately toothed gearing, either as spur or bevil wheels, or a combination of both, has been almost universally employed for first motions, the smaller powers being taken off pulleys by leather belts. The facility of taking small powers off drums to machines by means of belts, and the absence of noise and vibration, led to the adoption, in the United States of America, of broad leather belts for the transmission of large powers from the prime mover to the shafting in factories; and the success which has followed the adoption of these large belts there has led to their being adopted by many users of power in this country.

The object of the present paper is to bring before the Institution the plan of transmitting large powers by means of round ropes working on grooved wheels, which in some parts of this country has been largely adopted as a substitute for toothed gearing. The experience gained by the firm with which the writer is connected in this mode of transmitting power has extended over a period of thirteen years; and wherever it has been employed, either to replace toothed gearing in old or for new works, it has always given complete satisfaction.

In this mode of driving, the flywheel of the engine is made considerably broader than the flywheel of an engine having cogs on its circumference; and instead of cogs a number of parallel grooves for the ropes are turned out, the number and size of which

are regulated by the power to be taken off the flywheel. The power which each of the ropes will transmit depends upon their size and the velocity of the periphery of the flywheel. The ropes employed are of two sizes for large powers, namely $5\frac{1}{4}$ in. and $6\frac{1}{2}$ in. circumference; another size of rope, $4\frac{1}{4}$ in. circumference, is employed for small powers, but there is no definitely ascertained limit to the size of ropes that may be employed. Where large powers are required, and where large pulleys can be used, it is best to use heavy ropes, and the contrary when the opposite is the case.

The velocity of the periphery of the grooved flywheel and pulleys is generally arranged to be between 3,000 and 6,000 ft. per min.; and the velocity being settled and the power of the steam engine known, the number of the ropes required to transmit the power is then determined, from the experience that has been gained of the amount of power transmitted by ropes in previous cases. It is very essential that the right proportion between the diameter of the ropes and the pulleys should be obtained; if the diameter of the pulleys is too small, the rope in continually bending over them is apt to strain the strands and grind the core into dust, and on the size of the pulleys in a great measure depends the life of the rope. As a general rule the circumference of a pulley should not be less than thirty times that of the rope which works on it. In apportioning the distance between the driver and the driven shafts, great latitude may be allowed; a distance of from 20 to 60 ft. may be taken as a fair space.

The mode of applying a complete system of Rope Gearing is illustrated in Figs. 1 and 2, Plate 57, which show a factory for spinning and weaving jute belonging to Messrs. A. and J. Nicoll at Dundee, and fitted up by Messrs. Pearce Brothers, Lilybank Foundry of that town; this gearing has been working from June 1870. Fig. 1 represents a section of the factory, showing the engine flywheel A, which is 22 ft. diameter, and has eighteen grooves cut in its circumference; its width is 4 ft. 10 in. over all. The engine makes 43 rev. per min., and the velocity

of the periphery of the flywheel is therefore 2972 ft. per min. The power of the engine varies from 400 to 425 Ind. H. P.; the power transmitted by each of the ropes, which are $6\frac{1}{2}$ in. circumference, is therefore about 23 H. P. The power is transmitted to the ground floor by five ropes on to a pulley B, 7 ft. 6 in. diameter, the power required being 115 Ind. H. P.; that to the first floor by four ropes to a pulley C, 5 ft. 6 in. diameter, the power required being 92 Ind. H. P.; and that to the attic by four ropes on to a pulley D, 5 ft. 6 in. diameter, the power required being 92 Ind. H. P.; two shafts being required in this room, the power to the second shaft E is transmitted by horizontal ropes. On the other side of the engine shaft five ropes transmit 115 Ind. H. P. to a weaving shed, the pulley F being 7 ft. 6 in. diameter. The ropes should never be so heavily loaded as to draw them, even on short spans, to a near approach to a straight line; in this factory each rope, travelling at a velocity of 2972 ft. per min., transmits as above 23 Ind. H. P.; the tension on the rope is therefore $\frac{33,000 \times 23}{2972} = 256$ lbs., which is a very long way under the breaking strength of the ropes.

It will be seen from Fig. 3, which shows a section of two grooves with their appropriate ropes, that the ropes do not rest on the bottom of the groove, but on its V shaped sides; these sides are generally made at an angle of about 40° to each other. If the angle at which the grooves are formed is very obtuse, the ropes will slip; if too acute, much friction may be caused by the rope becoming wedged into the groove. As the sum of the tensions upon the two parts of a band is the same, whatever be the pressure under which the band is drawn or the resistance overcome, the returning side of the rope is as much slackened as the working side is tightened. It is therefore generally advisable, when it can be so arranged, to have the tight or driving side of the ropes at the bottom, so that the returning side may lap round the top of the pulleys, and consequently obtain extra bearing surface; when the opposite is the case, the ropes fall sooner out of the grooves, and so lessen the bearing surface. It is not always practicable to arrange this, and in the case of taking the power off both sides of the driving pulley, it is obviously impossible.

It will be noticed from Fig. 1 that none of the shafts of this factory are driven from the flywheel by less than four ropes, the strain on each rope being only, as shown above, 256 lbs.; it may therefore be supposed that a greater weight may temporarily be put upon a rope, in case any of the ropes should require to be tightened up, and this is often done. A rope is taken off at a meal hour, re-spliced, and put on again at the next stoppage of the engine, thus avoiding any necessity for night work or overtime. Night work should always be avoided, for besides the extra expense incurred, the work is never so well done by artificial light as it is done by daylight.

In Figs. 4 to 6, Plate 58, is shown the arrangement of rope gearing in the Samnuggur Jute Factory, Calcutta, which is a one-storey building, all the machinery, both spinning and weaving, being on the ground floor. The engines are placed near the middle of the building; they are about 1000 Ind. H. P., and make 43 rev. per min.; the flywheel is 28 ft. diam., and 6 ft. 7 in. width; the velocity of the periphery being 3782 ft. per min. The ropes are $6\frac{1}{2}$ in. circumference; eighteen ropes transmit the power to the right-hand or spinning side, and seven ropes to the left-hand or weaving side, making a total of twenty-five ropes; each rope therefore transmits 40 Ind. H. P. The tension on each rope due to this load at the above velocity is $\frac{33{,}000 \times 40}{3782} = 349$ lbs., which is rather a heavier load than in the factory previously described; all the shafts are also driven by more than one rope, with the exception of some of the line shafts in the weaving shed. Rope gearing was only adopted in this case after the most searching enquiry as to its suitability for working in the warm and humid climate of Calcutta, and its adoption has been attended with very satisfactory results, both in this case and also at the Sealdah Mills in Calcutta.

In Plates 57 and 58 are shown the arrangements adopted when the factories have been specially designed for rope gearing; but this gearing has often been applied to replace toothed gearing in mills already built. The plan then adopted is to put in a new grooved flywheel, or to place grooved segments upon the existing flywheel, when the speed is sufficiently great to allow of a limited number of

ropes being employed, and the width of the wheel pit is also sufficient for the purpose; but if this plan cannot be adopted, grooved pulleys are put on the second motion shaft, and the ropes carried to the different storeys of the mill. It has even sometimes been necessary to put in a counter-shaft, so as to gain speed and get sufficient length between the centres of the shafts on which the pulleys are placed.

A comparison has now to be made between the system of rope gearing and the other two systems in use at the present time. The system in most general use is toothed gearing; in this the first driver is the spur-wheel fitted on the crank shaft of the engine, into which is geared the driven pinion of smaller size. In order to ensure these two wheels working well, it is absolutely essential that the centres of the engine shaft and the pinion shaft are rigidly fixed at the correct distance from each other, and that the teeth of the two wheels are accurately of the same pitch and size. The first of these objects is attained by making the engine bed, in a horizontal engine, a strong rigid casting resting on an expensive ashlar foundation; or in a beam engine the foundations are alone depended upon. If these objects are attained, the wheels ought to work smoothly and without much noise; but how often this desirable result is attained requires only a walk to be taken through the streets of a manufacturing town, to ascertain by the rumbling noise sometimes heard at a distance of several hundred yards that all is not as it should be for the safe and economical transmission of the power of the steam engine. If the factory consists of more than one storey, the power has to be taken from the second motion shaft by means of an upright shaft and bevil wheels, requiring heavy wall-boxes, and strong walls to keep the wall-boxes in their places: the whole object in the construction of the factory being to secure a rigid and immovable structure, a matter which is very difficult to attain.

In the case of rope gearing, the ropes by which the power is transmitted consist of an elastic substance; and their lightness, elasticity, and comparative slackness between the pulleys, are highly conducive to their taking up any irregularity that may occur in the

motive power. This accounts for the slight attachments that are required for shafting driven by ropes from a grooved flywheel; and it is the same with all the bearings throughout the mill, the shafts in the various flats only requiring a light wall-box or bracket, or the bearing may be carried on a column of the mill. The cost of fitting up a mill with rope gearing is considerably less than with toothed gearing, when the shafts to be driven revolve at a high speed; but the cost is about the same in other cases. It is however rather difficult to give exact figures for this comparison, one great saving being in the foundations of the engine, the wall-boxes, and the extra strength of the walls required for upright shafts.

The great advantage of rope gearing however is the entire freedom from any risk of a breakdown; when a rope shows symptoms of giving way—and ropes always give symptoms of weakness long before they break—the weak rope can be removed and another put in its place at any meal hour or evening. The cost of the maintenance of ropes for transmitting 400 Ind. H. P. has been found to be £20 per annum, or about £5 per 100 Ind. H. P. per annum. This is made up of the cost of renewal of the ropes, and occasional wages for tightening them. Some ropes have been found to run $10\frac{1}{2}$ years; but as a general rule the life of a rope may be said to be from three to five years, though even five years has often been much exceeded.

The friction of rope gearing has been found to be, for high speeds, considerably less than that of toothed gearing; but the writer regrets not being able to give definite information on this point, which is a very important one to those contemplating altering their gearing or building new works. The reason why no definite information can be given—beyond the universal impression of those who have adopted them, that ropes require less power to drive than toothed gearing—is that, in all cases where rope gearing has been substituted, other alterations have been made at the same time, or the engines were after the alteration driven at an extra speed of 10 or 15 rev. per min. However, everyone who has substituted rope gearing for toothed gearing also agrees in bearing testimony to the great improvement and steadiness of driving obtained after the

alteration, and that the machinery is enabled to turn off a greater weight of yarns in the same time. The tendency at the present time, with the introduction of shorter hours of labour and with foreign competition, being to increase the speed of shafting and machinery, the ability by this means to increase the speed of the shafts must be of great advantage to those who own old mills, the toothed gearing of which is generally driven as fast as it is safe to drive it.

The ropes used for rope gearing are made of hemp carefully selected: the qualification of a good rope being that the fibres should be as long as possible, and that the rope should be well twisted and laid, and yet be soft and elastic. It is also very important that the ends of the rope should be united by a uniform splice, which should not be of a greater diameter than the other part of the rope; to effect this object the splice is made about nine or ten feet long for a rope of $6\frac{1}{2}$ in. circumference.

The comparison between rope gearing and toothed gearing having been made, it remains to compare ropes and leather belts, which latter have been lately used in the manufacturing districts of Lancashire and Yorkshire for the transmission of large powers. The writer has not been able to obtain very satisfactory information as to the amount of power absorbed in friction by large belts; in some cases it has been said to be more and in some less than with toothed gearing. The most trustworthy information he has obtained is in the case of a four-storey woollen mill, where an upright shaft with bevil gearing was replaced by two belts, one 22 in. wide and the other 27 in. wide, the power transmitted being 400 Ind. H. P., and the speed of the belts 3000 ft. per min.; the driving pulleys are on the second motion shaft. In this case the power is stated to be the same with the belts as it was before the alteration; but, as in the case of rope driving, the "turning" is found to be much superior to what it was before the alteration. The width of the pulleys for ropes is generally rather less than for belts transmitting the same power; but there is some difference of practice as to the width of belt used for transmitting a certain power. The cost of

hemp ropes is considerably less than of leather belting, the cost of hemp ropes being about 1*s.* per lb. against 3*s.* per lb. for leather belts. The grooved pulleys for ropes cost more than plain pulleys, but making allowance for this, the total cost of ropes and grooved pulleys for transmitting a given power does not exceed one-half or two-thirds the cost of leather belting and flat pulleys. The advantage of ropes over belting however lies in the power being divided up into a number of ropes, so that in the case of any one of the ropes showing symptoms of weakness, that rope may be removed by stopping the engine for a few minutes, the remaining ropes continuing to do the work until the regular time of stoppage of the engine. In the case of belting, as only one belt is employed to drive one flat of a mill, if anything were to occur to the belt, the whole of that flat would be stopped until the belt was repaired.

Judging from the practice adopted, the comparative amount of power transmitted by certain sizes of ropes and widths of double belts, the writer finds that a rope of $6\frac{1}{2}$ in. circumference does about the same amount of work at a given speed of say 3000 ft. per min. as a belt 4 in. wide. This width however represents the smallest width adopted as a rule, 5 in. corresponding to the American practice; but taking a 4 in. belt, the bearing surface of a rope of $6\frac{1}{2}$ in. circumference on the sides of the grooves in a 4 ft. 6 in. pulley will be half the circumference, or 85 in., and allowing the rope half an inch width of bearing on each side, or one inch for both sides, the total bearing surface is $85 \times 1 = 85$ sq. in., whilst the belt has $85 \times 4 = 340$ sq. in., or four times the amount. Consequently, in order that a rope of $6\frac{1}{2}$ in. circumference may transmit as much power at the same tension as a 4 in. belt, the effective pressure per sq. in. of the bearing surface of the rope on the pulley must be at least four times as great as that of the belt.

In order to obtain some information bearing on this point, a set of experiments have been made by Mr. A. W. Pearce, at Lilybank Foundry, Dundee, the results of which are given in the Table appended. The experiments were made with the materials at hand; both the pulleys were just as they came from the lathe, and equally smooth, and they were nearly the same size, as named in the table.

Comparing together Nos. 2 and 5 experiments, it is seen that an ungreased rope of 6 in. circumference, with 336 lb. suspended at one end, and passing over a 4 ft. 9 in. grooved pulley which was at rest, required only 28 lb. at the other end to prevent slipping; whilst a half-worn good single leather belt 4 in. wide, with the same load of 336 lb. at one end, and passing over a 4 ft. 6 in. pulley, required 113 lb. at the other end to prevent slipping, or about 4 times as much as with the rope. The bearing surface of the rope would be only about 1-4th that of the belt, and the effective pressure per sq. in. of the bearing surface of the rope was consequently in this case 16 times as great as that of the belt. In the experiment No. 4 a double leather belt 6 in. wide and $\frac{3}{8}$ in. thick, with the same load of 336 lb. at one end, and passing over a 4 ft. 6 in. pulley, required 98 lb. at the other end to prevent slipping, or $3\frac{1}{2}$ times as much as with the rope of 6 in. circumference. The experiments show however such a great difference between the results with different sizes of ropes, as to make it impossible to come to any definite proportion between the friction of ropes and belts; but they show, as was to have been expected, that ropes have a considerably greater hold on the V shaped grooves per sq. in. of bearing surface than flat belts have on pulleys.

The writer has been informed that in the United States several rolling mills are driven by means of flat leather belts, and that very satisfactory results are obtained by their use; and he wishes to draw the attention of members engaged in this department of manufacture to the suitability of rope gearing for this purpose. Although he is not aware of any practical example of its having been applied to driving rolling mills, he is confident that from the slackness with which the ropes can work, and the hold they have on the grooves of the pulleys, they would be admirably adapted for taking up the shock which is thrown upon the gearing of a train of rolls when the iron enters the rolls.

Experiments on the Friction of Ropes and Leather Belts on cast-iron turned pulleys.

No. of Experiment.	Rope or Belt.	Circumference of Rope, or Width of Belt.	Diameter of Pulley.	Load suspended at one end.	Weight required at other end to prevent slipping.		Remarks.
					Ungreased.	Greased.	
		In.	Ft. In.	Lb.	Lb.	Lb.	
1	Rope.	7	4 9	336	56	102	Rope somewhat worn.
2	do.	6	4 9	336	28	90	Rope new.
3	do.	$5\frac{1}{4}$	4 9	336	14	...	Rope new.
4	Belt.	6	4 6	336	98	133	Double Belt $\frac{3}{8}$ in. thick.
5	do.	4	4 6	336	113	...	Single Belt half worn.

NOTE.—The rope pulley used in these experiments was grooved for $6\frac{1}{2}$ in. circumference of rope.

Mr. Durie exhibited a specimen of a rope 7 in. circumference, which showed very little wear after working $4\frac{1}{2}$ years under a strain of 205 lbs. at a speed of 2900 ft. per min., transmitting 18 Ind. H. P. Also a specimen of a new rope showing the mode of splicing.

The President remarked that Manchester was the place where leather belting was more used than almost anywhere else; and there were doubtless many of the Members who could give the results of experience upon the subject.

Mr. E. J. C. Welch said the subject of the transmission of power by means of either belts or ropes, instead of by toothed wheels, was occupying an unusual amount of attention in the Lancashire district at the present time. In the paper just read an account had been given of the particular arrangements adopted in one or two instances; that these arrangements were sufficient for their purposes might be inferred from the fact that they were working; but there was nothing to show that they were not greatly in excess of the requirements; and that being so, it was not possible to deduce from them any definite formulæ or rules for the correct proportioning of the various parts. The arguments adopted throughout the paper entirely disregarded the principles upon which the action of rope and belt gearing depended. It was stated that "the ropes should never be so heavily loaded as to draw them, even on short spans, to a near approach to a straight line"; but it was difficult to know what was meant by this expression, as it would require an *infinite* force to draw a rope up to a really straight line horizontally, and the rope would of necessity break before it was brought even "to a near approach to a straight line." The normal tension on the belt or rope could be ascertained exactly, that is, the tension requisite to transmit a given amount of power.

With regard to the angle of the rope grooves in the iron pulleys, it was clear that, if the angle was so acute that the tangent of its half was less than the coefficient of friction between the iron and the rope, the rope would then hang in the grooves. The most

suitable angle therefore would probably be double that whose tangent was equal to the coefficient of friction.

In horizontal belts or ropes the importance of having the tight or driving side at the bottom was not fully realised at all times; and it was desirable for it to be known that, as the transmitting power of the belt increased as 10^a (where a was the angle of contact with the pulley), the increase in the arc of contact caused by the slack side of the rope being on the top *very materially* increased its hold upon the pulley. It was remarked that the advantage of ropes over belting lay in the power being divided up into a number of ropes; that however was frequently, and as advantageously, done with belts, working on pulleys divided by flanges.

In the comparison drawn between a rope of $6\frac{1}{2}$ in. circumference and a belt of 4 in. width, each transmitting the same amount of power, the argument adopted in the paper was clearly fallacious. It assumed that the coefficient of friction was the same in both cases; but even had this been so, the statement made about the relative pressure of the rope and of the belt upon the pulley was still incorrect, because with grooved rope pulleys of the same size as the belt pulleys, and with a tension of rope equal to that of the belt, the pressure per square inch of contact surface was not simply inversely as the extent of that surface; but in the case of the grooved pulley it was the product of the radial pressure at every point multiplied by the cosecant of half the angle formed by the two sides of the groove. Then if the series of these pressures round the arc of contact was integrated, the requisite normal tension N on both sides of the rope when at rest (being half the sum of the tension on the tight and slack sides when in motion) was found to be

$$N = \frac{R\,(10^{0{\cdot}00758\,a\,f\,\operatorname{cosec} x} + 1)}{2\,(10^{0{\cdot}00758\,a\,f\,\operatorname{cosec} x} - 1)}$$

in which R = the force actually transmitted to the surface of the pulley, being the difference between the tensions on the tight and slack sides of the rope; a = the angle of contact (in degrees);

f = the coefficient of friction; and x = half the angle formed by the two sides of the groove in the pulley. In the case of an ordinary pulley and belt the value of N became

$$N = \frac{R\,(10^{0\cdot00758\,af} + 1)}{2\,(10^{0\cdot00758\,af} - 1)}$$

For example, assuming that it was required to transmit in each case to the surface of the pulley an effective force of say 10,000 lb., and that the arc of contact was 180°, and the angle of the grooves 40°, so that cosec x = cosec 20° = 2·924; and assuming further that the coefficient of friction (0·423) which applied to leather belts and iron pulleys also held good for hemp ropes; then in the case of the rope and grooved pulley,

$$N = \frac{10{,}000\,(10^{0\cdot00758 \times 180 \times 0\cdot423 \times 2\cdot924} + 1)}{2\quad(10^{0\cdot00758 \times 180 \times 0\cdot423 \times 2\cdot924} - 1)}$$

$$= 5000 \times \frac{10^{1\cdot68756} + 1}{10^{1\cdot68756} - 1}$$

$$= 5200 \text{ lbs. nearly}$$

($10^{1\cdot68756}$ being the number whose logarithm is 1·68756, namely 48·7035)

In the case of the leather belt

$$N = \frac{10{,}000\,(10^{0\cdot00758 \times 180 \times 0\cdot423} + 1)}{2\quad(10^{0\cdot00758 \times 180 \times 0\cdot423} - 1)}$$

$$= 5000 \times \frac{10^{0\cdot5771} + 1}{10^{0\cdot5771} - 1}$$

$$= 8600 \text{ lbs. nearly.}$$

($10^{0\cdot5771}$ being the number whose logarithm is 0·5771, namely 3·7766)

Thus for the rope only to transmit the same power as the belt, the diameters of the pulleys and their speeds being the same in both cases, the normal tension of the rope was required to be only $\frac{52}{86}$ or about 60 per cent. of that of the belt, and not equal to it as was stated in the paper.

It was commonly thought that if two pulleys were connected together by a belt they would run at the same surface velocity; that

is, if the pulleys were equal in diameter they would make the same number of revolutions in a given time. This was however not the case, because the driving pulley would run faster than the one which was driven, the difference in the velocities increasing as the resistance of the driven pulley was increased; and this was due to the belt being stretched as it approached the driving pulley, and re-contracting as it returned towards the driven one.

The short table of experiments given in the paper certainly appeared to present a wide diversity of results, which was probably due to the different bearing that the ropes of various sizes took in the groove of the pulley; for whilst several sizes of ropes were tried, from $5\frac{1}{4}$ to 7 in. circumference, they all differed from the size, $6\frac{1}{2}$ in., for which the pulley used was stated to have been grooved. In the case of leather belting and iron pulleys, a coefficient of friction had been deduced from the average of some two hundred distinct experiments; and it was desirable that equally reliable coefficients should be established for other materials used for belt or rope gearing. Having deduced the coefficient of friction f for each of the five experiments given in the table, he had found the results were as follows:—

No.		Coefficient of Friction.	
		Ungreased.	Greased.
1	Rope	0·195	0·129
2	do.	0·270	0·143
3	do.	0·345	...
4	Belt	0·392	0·295
5	do.	0·347	...

The mean value of f deduced from the five data in experiments Nos. 1, 2, and 3 was 0·248, which was not the same as the mean of the five deduced values of f for those experiments; for, instead of taking simply a mean between the five values of f itself, the mean value of the ratio of the weights at the two ends of the rope was taken, and a value for f deduced from it.

In order to obtain the coefficient of friction f for a rope of any material working on a grooved pulley, the angle formed by the two sides of the groove being called $2x$, it was only necessary to fix the pulley upon a fast horizontal shaft so that it could not revolve,

and to place the rope in the groove with its ends hanging down of an equal length on each side, and to attach a weight Q to one end of the rope, and to the other end a heavier weight P such as would only just draw up the weight Q. For if the series of the infinitely small differences of tension around the whole arc of contact was integrated, the relation between the final tensions P and Q at the two ends of the rope was found to be

$$\frac{P}{Q} = 10^{0{\cdot}00758\, a\, f\, \operatorname{cosec} x}$$

and the angle of the arc of contact being 180°,

$$\frac{P}{Q} = 10^{0{\cdot}00758 \times 180 \times f \operatorname{cosec} x} = 10^{1{\cdot}364\, f \operatorname{cosec} x}$$

$$\text{Therefore } \log \frac{P}{Q} = 1{\cdot}364\, f \operatorname{cosec} x, \text{ and } f = \frac{\log \frac{P}{Q}}{1{\cdot}364 \operatorname{cosec} x}$$

and to avoid division it was convenient to multiply instead by the reciprocals of 1·364 and cosec x, when the formula became

$$f = 0{\cdot}733 \sin x \log \frac{P}{Q}$$

$$\text{For ordinary flat belting } \frac{P}{Q} = 10^{0{\cdot}00758 \times 180 \times f} = 10^{1{\cdot}364\, f}$$

$$\text{Therefore } \log \frac{P}{Q} = 1{\cdot}364\, f, \text{ and } f = \frac{\log \frac{P}{Q}}{1{\cdot}364} = 0{\cdot}733 \log \frac{P}{Q}$$

The smallest diameter of pulley found desirable in practice had been stated in the paper to be thirty times the diameter of the rope; but it must be borne in mind that the sectional area of the rope would also vary inversely as the diameter of the pulley, for the transmission of a given power at a given number of revolutions per minute. Therefore it was evident that all the conditions must be taken into account at the same time, which was done as follows:—putting d = diameter of rope in inches when one only was used, so that diameter of smaller pulley = 30 d; H = indicated horse power to be transmitted; V = number of revolutions per minute made by smaller pulley; T = safe working strength of rope in lb. per sq. in. of section; R = force actually transmitted to the surface of the pulley, or the difference between the tensions P and Q of the tight and slack sides respectively of the rope when at work. Then $H = \frac{R \times 3{\cdot}1416 \times 30\, d \times V}{12 \times 33{,}000}$; therefore $d = \frac{4201{\cdot}68\, H}{V\, R}$. But, by

the theory of the action of ropes on grooved pulleys, $R = P - Q = P \times \left(1 - 10^{-m}\right)$, where $m = 0{\cdot}00758\, a\, f \operatorname{cosec} x$. And P being the tension in lbs. of the tight or driving side of the rope when at work was therefore the maximum tension, which must not exceed the safe working strength of the rope; so that

$$P = 0{\cdot}7854\, d^2 \times T, \text{ and } R = 0{\cdot}7854\, d^2 \times T \left(1 - 10^{-m}\right)$$

$$\text{Therefore } d = \frac{4201{\cdot}68\ H}{0{\cdot}7854\, d^2\, V\, T \left(1 - 10^{-m}\right)}$$

$$= \sqrt[3]{\frac{5349{\cdot}733\ H}{V\, T \left(1 - 10^{-m}\right)}}$$

Should it be found desirable to use a number of smaller ropes, instead of a single large one, it could readily be so arranged; and if the same proportion of 1 to 30 between the diameter of the rope and that of the pulley were still retained, it was necessary that, as the diameter of the ropes was diminished, the diameter of the pulley also should be diminished in the same proportion. But this reduced pulley would have a correspondingly reduced surface velocity; therefore, in order to transmit the same horse power as before, at the same number of revs. per min., it was requisite to transmit more force at the surface of the pulley; and to do this without exceeding the maximum tension to be borne by each unit of area of rope, it became necessary further to increase in like proportion the number of ropes to be used. Let b = number of ropes to be used instead of one; d = diameter of rope when one alone was used, as ascertained by previous formula; l = diameter of each rope when b ropes were used; then diameter of smaller pulley when b ropes were used = $30\, l$. The sectional area of the single rope would be to that of one of the smaller ropes as d^2 to l^2; and the force to be transmitted at the surface of the then proportionately smaller pulley would be to that at the surface of the original pulley as d to l. Therefore the number of ropes b to be used would increase as the area of the single rope to the area of one of the smaller ropes, or as $\frac{d^2}{l^2}$; and further as the surface velocity of original pulley to the surface velocity of reduced pulley, or as $\frac{d}{l}$; hence $b = \frac{d^2}{l^2} \times \frac{d}{l} = \frac{d^3}{l^3}$; and $l = \frac{d}{\sqrt[3]{b}}$. From the foregoing formulæ all the details in connection with rope driving gear could be obtained.

Mr. A. Paget said that some years ago he had been desirous to get all the published information he could on the subject of the friction of ropes on grooved pulleys, to aid him in some experiments he was making; but he had not obtained any that was satisfactory. He then made a series of upwards of 900 experiments to ascertain the proper coefficient of various sorts of ropes under different circumstances on pulleys of different materials and with different forms of grooves. But on comparing them he had found the results were so different among themselves, under circumstances differing so slightly, that he did not consider them worth preserving; with the same rope on the same pulley on several different days he got coefficients of friction varying as much as 50 per cent., the friction being double on one day what it was on another. That was due he presumed to the different effects that the weather produced on the rope, and also probably on the iron. Of course if the pulleys had been kept constantly running the surface of the iron would have been kept in a more constantly equal condition; but the pulleys on which he had experimented were used at intervals only and were also stationary pulleys, as those used in the experiments given in the paper appeared to have been, with a weight on the one side and a heavier on the other, which was increased until the moment the rope started. Many different qualities of rope were used, and absurdly different results were obtained; sometimes the coefficient of friction would vary to the extent of three or four times, with a slight variation in the quality of the rope. He thought therefore that the table of experiments accompanying the paper would not be at all sufficient to deduce an average from; and notwithstanding the number of experiments that he had made, he thought the subject was really such a large one that one coefficient could not be safely given for the friction of ropes in grooved pulleys.

He noticed that on one point the author of the paper had arrived at the same conclusion as he had himself, that 40° was about the best angle for the pulley grooves in order to get the best results and the longest wear out of the ropes. That was the conclusion he had come to from the experiments he had made, and he had since then always adopted that angle; he had formerly used 30°, but he found

that 40° would not wear the rope unduly. If a complete series of experiments could be conducted to elucidate the various coefficients of ropes on grooved pulleys, he thought it would be of great use to engineers with regard both to this question of rope gearing and to other questions.

Mr. E. J. C. Welch observed that if the angle of 40° were shown to be the best, there could be very little doubt that the coefficient of friction was 0·364.

Mr. E. A. Cowper mentioned a simple experiment that he had repeated many times, by hanging over a fixed pulley or drum a piece of rope, or string, or tape, or almost any ordinary kind of flexible material; and hanging a weight of 3 on one end and 1 on the other, if the surface were a little smoother than usual the weights would just run, but if the surface were an ordinary iron drum they would not run. An ordinary fair leather strap would stand an ultimate tensile strain of 5 lb. on every square 1-8th inch (320 lb. per sq. in.); that must be the heaviest ultimate pull, the pull on the slack side being one third of the amount, and of course there would be a margin within the ultimate strain for the working strain. In this way it could be roughly determined what power any pulley would transmit. The result arrived at was only approximate, as it could not be ascertained very exactly; he agreed that the experiments on this subject varied considerably, but certainly not so much as 50 per cent. The object was to take what was safe in ordinary practice; there might be a slippery day and then a dry day, but it was the slippery day that would govern the power transmitted, and not the dry day. If the drum or pulley got ever so little rusty, the leather strap had a greatly increased hold upon it; but the drum must be taken in a fair ordinary condition. Hammers in forges had often been driven by belts of pit rope—wide bands made with rope,—and they answered very well indeed.

A peculiar kind of driving band, intended for a special purpose, to be used in damp places or in places sometimes damp and

sometimes dry, varying in temperature, had been made with copper wire of small size, which was wound round and round the two pulleys till a good body of material was obtained, the two ends being fastened together; then this body of wire, not twisted but simply wound, was paid over or bound with tape, and it made a satisfactory driving band. It answered a great deal better than gut, because gut with varying temperature and varying humidity of the atmosphere was a very bad material for the purpose, to say nothing of the trouble of hooks and eyes for the fastenings. The rope arrangement described in the paper certainly seemed to be an admirable one for large powers; of course the copper-wire band that he had alluded to was for transmitting only a moderate power, perhaps not more than 2 H.P.; but for the large powers referred to in the paper the rope gearing described seemed to be a very satisfactory arrangement.

With the angle of 40° that had been named for the rope grooves the friction of the rope upon the two sides of the groove amounted to nearly three times as much as if the rope were working on the surface of a plain drum without grooves. In the illustration he had mentioned of a rope passing round half the circumference of a drum or pulley, the multiplication of 3 to 1 in the tension of the two portions of the rope by the bite of the drum or pulley would be largely exceeded when a V shaped groove was used.

In America he understood that wide leather driving bands had been used to a large extent; there was one in the Exhibition in Philadelphia 5 ft. wide and 186 ft. long, and others in use at Lowell 3 ft. wide. It had been said that they were now being partly superseded by steel bands, like band saws without teeth; and no doubt steel bands passing over large pulleys would convey a large amount of power, as of course the tension upon them could be much greater than upon a rope or a leather band; but he had made careful enquiries from a friend in U.S. America, and found he had been mis-informed as to their use there.

Col. Clay mentioned that he had once had a crane driven by a rope, and the experience of its working had been most unfavourable.

It was a very heavy travelling crane, and carried 30 tons; the rope did not run at a very excessive speed, but the trouble it gave was such as to cause great objection. A hemp rope that was first tried would not last above two or three days. Then cotton was tried, and the first cotton rope answered much better; but when another rope was wanted, the first being worn out, it happened to be the time of the American war, when long-staple cotton was almost impossible to be obtained; and the cotton with which the ropes had therefore to be made was such that it was not much better than hemp. The difficulty was only partially got over by having a band made of hide; that answered better, and he believed it would be found that a hide band would answer moderately satisfactorily—much better than any rope.

In regard to the statement in the paper that rolling mills had been driven by leather belts, he had had a little experience on that point, and had found the leather belts work satisfactorily; but he should not like to drive rolling mills by means of ropes. If there were no other reason, the quantity of fire continually flying about in ironworks was such that the ropes would soon come to destruction from that cause alone. Then the great alternations of damp and dryness were also a great objection to the use of ropes for such a purpose.

Mr. John Musgrave believed rope driving was much more used than the majority of engineers were aware of; and he showed drawings of some of the mills to which the plan had been applied by their own firm. One was that of the Howrah Jute Spinning and Weaving Mill, Calcutta (Plate 59), which was driven by a pair of horizontal compound engines on the tandem principle, running at 40 rev. per min., and capable of indicating about 800 H. P. with 80 lb. boiler pressure; the power of the engines was transmitted from a fly pulley or drum of 57 tons weight, 28 ft. diam., and 5 ft. 9 in. wide on the face, by 22 ropes of $6\frac{1}{2}$ or 7 in. circumference, running at 3520 ft. per min.; that he thought was a very good plan, to have the drum of great weight to carry it well over the centre. Another case was the Budge Budge Jute Weaving Mill, also in

Calcutta (Plate 60), which was driven by a pair of 25 H. P. horizontal compound engines on the tandem principle, running at 50 rev. per min. with 70 lb. boiler pressure; the fly pulley was 18 ft. diam., and 3 ft. 4 in. wide on the face, for 15 ropes of 5 in. circumference, running at 2850 ft. per min.; the ropes conveyed the power to an 8 ft. pulley on the first shaft in the weaving mill, from which it was carried forwards to the other shafts by the number of ropes necessary for the power required to drive the machinery. The same plan was also being applied to the Attleborough Doubling Mill now being erected at Nuneaton, which would be driven by a compound engine running at 45 rev. per min., the fly pulley being 22 ft. diam., 3 ft. 8 in. wide on the face, grooved for 14 ropes of 7 in. circumference, running at 3150 ft. per min.; the mill was four storeys high, and the power was transmitted direct to each room by two ropes over a pulley 6 ft. diam., giving 70 Ind. H. P. for each room.

The use of ropes for driving was originally introduced he thought by Mr. Combe in Belfast many years ago; but the ropes were not then made so well he believed as at present, and did not run at so high a speed as now. Ropes had not been used in Belfast so much as they were beginning to be used now. In Dundee he thought rope driving had been more extensively adopted than in Lancashire; but there were other works in Lancashire besides their own at Bolton that were now making great preparations for rope driving.

Mr. W. Inglis considered the paper did not give an adequate idea of the extent to which ropes were used for driving; they were largely used now, not only in Scotland and Ireland but in England also; in Lancashire the system seemed to be growing in favour. At the works with which he was connected (Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton) a considerable number of rope driving pulleys had been made for several years past, for mill engines of different sizes up to 700 Ind. H. P.; and they had a good many in progress now. In regard to the form of the grooves, they had followed the practice of Messrs. Combe and

Barbour of Belfast, which was similar in angle to that given in the paper, and so far as he was aware there had not been any difficulty experienced with the ropes. In no case where they had applied the system had he heard of any failure or disappointment.

Mr. Jeremiah Head remarked, in reference to the application of ropes for driving trains in rolling mills, that in rolling heavy sections of iron, such as plates, the engine in all the cases that he knew of was made to run at a greater speed than the train; and this was done in order to keep the size of the engine down as much as possible, and to obtain the advantage of a quick speed for the flywheel. In that case therefore the power was conveyed ordinarily from the engine shaft to the first motion shaft of the train by spur wheels in a diminishing ratio, and when so worked nothing could answer better than they did. Modern rolling mills for rails were now sometimes made to work direct, without any gearing at all; in that case therefore there was clearly no occasion for the introduction of rope gearing. But in rolling small sections of iron, such as in guide mills, it was often necessary to increase the speed to something considerably above that of the engine shaft; it was possible that in such cases rope gearing might be applicable, because when the speed was multiplied spur wheels did not always act well, and another plan—Robertson's frictional gearing—had also he believed been found apt to get out of order. This appeared to him to be the only case in which ropes would be found applicable to rolling mills, and then only in the case of very small mills. He agreed in the opinion that the amount of fire which was flying about ironworks, in the shape of hot iron and sparks from the forges and rolling mills, formed a serious objection to the use of ropes; it often happened that from the hammers and rolls pieces of hot cinder came flying out, and these might easily lodge in a hemp rope and set it on fire.

Mr. W. Smith mentioned that at the Colonial Rope Factory of Harris Smith and Co. at Great Grimsby in Lincolnshire, from 1830 to 1837, ropes had been employed by his father, the late

Mr. Andrew Smith, for taking off the power from the engine and communicating it to the first motion shaft. The plan was very commonly adopted in connection with rope works, where the driving rope employed was known as the fly rope, for working the traveller or "equaliser" from end to end of the rope walk. The machinery in connection with the flax spinning mills at the same place, as well as the rope factory, was also driven by means of rope gearing. The rope factory was about 400 yards long, and the engine was 100 H. P.; and the method of driving by ropes was very satisfactory. The motive for adopting that plan he believed had been not only on account of the noise made by gearing, but also on account of the vibrations communicated by spur gearing to the walls and other parts of the building, which was built upon the sandy foreshore of the river Humber. The result of the experiments then made had shown he thought that the V shaped groove was not at all satisfactory; and he believed the grooves used had been semicircular at the bottom, the rope ultimately resting in the bottom of the U groove. Mr. Combe's pulleys had a defect which told very much against a continued use of hemp ropes upon them, namely that the bearing for the ropes was not uniform, the pulleys being constructed of a series of open bars like a whim, and the friction soon wore the ropes out; that was the main defect in Combe's application of the rope system.

Mr. T. Beeley said that, having had occasion last year to change the power in a small cotton mill, where it was more convenient to drive with straps or ropes than with spur gearing, he had made enquiries as to the relative cost and durability of straps and ropes, and as to how the ropes were going on, and how they were liked by those who had them; and to the many enquiries made he had received without a single exception satisfactory replies as to the use of ropes. A pair of engines was accordingly put down to give 300 Ind. H. P., the flywheel 22 ft. diameter grooved for 12 ropes of 6 in. circumference, driving fore and aft on to two 5 ft. drums, each at a distance of 31 ft. from the flywheel, 6 ropes being led to one of the drums and 5 to the other; the section of the grooves was

similar to that shown in the drawing accompanying the paper. No inconvenience was found from driving aft, nor from any difference of speed on dry and wet days, the second motion shaft gave a uniform speed under all the variations of condition such as obtained in a cotton factory. The speed at which the ropes ran was 3500 ft. per min.; they had now been working eight months, and the result had been in every way satisfactory. For straps to take off the same power the estimated cost was £324, while the cost of the ropes had been only £73. When making enquiries respecting the durability of ropes from some of the proprietors of mills in Ireland, he had learnt that one of them, who had been running one engine and taking off the power from it through ropes for $6\frac{1}{2}$ years, without having changed any of the ropes, was putting down another mill at the time, and was preparing to take off 600 H. P. from another flywheel by means of ropes. The new mill had since been got to work, and he was informed it was working as satisfactorily as the previous one which had been going for so many years.

Mr. W. W. Hulse observed that in the paper there was not any mention of Messrs. Combe and Barbour of Belfast, with whom the system of "rope gearing" originated. They had never ceased from the first to make and apply it, both in Ireland and this country; and when recently engaged at their works he was surprised to see such an extensive business doing in it.

He remarked on the great advantage the Institution was deriving since the system of issuing printed papers previous to meetings had been adopted. The able discussion of the present paper showed that a great amount of time and thought had been given to the subject after the receipt of the paper, and formed a valuable supplement to the paper.

Mr. W. Richardson said with regard to the use of the grooved pulleys for taking power from ropes, and the proper angle for the groove, he had had a good deal of experience with hoists for which large ropes had to be used; and he had found that the life of the rope was three or four times as long if it ran in a semicircular

groove, as compared with its life in a V groove. The ropes failed from two causes when running in V grooves: either the strands were cut by the friction of one against another inside, or the friction of the pulley wore out the strands individually on the outside. Now if the rope ran in a semicircular groove of the form of itself, neither of these causes of destruction was so liable to occur, and the rope had a much longer life. If friction enough were not obtained with the round groove that gave the longest life, then a greater number of ropes working in round grooves should be used, so as to get the amount of friction required without destruction of the ropes; that he thought was the end to be arrived at in practice, whatever the theory might be.

With regard to rolling mills running at quick speeds, driving by straps or ropes was found decidedly advantageous. Some time ago he had an 8 inch mill driven by spur gearing, and he never knew when the wheels were going to break. Some of the coupling spindles were longer than usual, to deliver the bars from the finishing rolls so as to clear a pillar. These lengthened spindles allowed an increase of torsion, which acted as a spring; and when a number of bars in the mill happened to leave the rolls at the same time, this spring was released suddenly and caused the wheel on the end of the line of rolls to flirt back and break the cogs. About three years ago this gearing was removed, and a strap 30 in. wide travelling at 3000 ft. per min. was substituted, and since then he had had no breakage.

Mr. E. A. Cowper drew attention to the description given at a former meeting (see Proceedings Inst. M. E. 1874 page 56) of the mode employed at Schaffhausen for driving a very large amount of power with wire ropes. On that occasion it had been very distinctly put forward that the wire rope ought to be treated in the most careful manner possible. There was no rubbing at all against the sides of the groove in the pulley, the rope not only lay on a flat surface in a groove wider than itself, but the flat surface at the bottom of the groove was made of wood, willow being recommended as the best, and thus the longest life of the rope was ensured. The life of

a rope depended upon how it was treated; and the wire ropes being very long, they would perhaps become a very heavy item if there were any great wear and tear upon them. In the case described the ropes ran at 53 miles an hour, transmitting 540 H. P.; and the pulleys were 15 ft. in diameter.

Mr. F. Preston supported the statement that ropes were being considerably more used now for driving machinery than was generally known. Having been concerned in getting information on the subject with a view to the building of a new mill in Manchester, he had been to Dundee, where the plan was very extensively used, and had visited many large establishments and obtained the opinions of those who had been running ropes from three to thirteen years. On asking the owners what they would do if they were building new mills, the answers received were all in favour of using the ropes, except in the case of one mill, where the owner was using both gearing and ropes, and was divided in his opinion. The best results were found in mills where the grooved flywheel or driving drum was running at not less than 3000 ft. per min., and the speed of the next pulley was not less than three times that of the flywheel. The power transmitted per rope was found by indicator diagrams to range from about 18 to 31 Ind. H. P. The highest results that he had heard of were at one mill where 30 Ind. H. P. per rope was transmitted, the ropes running at 3300 ft. per min.; and at another mill where 560 Ind. H. P. was transmitted by 18 ropes, giving about 31 Ind. H. P. per rope. A weaving shed built a few months ago by Messrs. Holden at Bradford was driven by ropes entirely, and could be seen by any one interested in rope gearing; and he was now making plans for two new factories that would be entirely driven by ropes, one in this country and one abroad.

The President enquired what provision was made for protecting the ropes by fencing them in according to the machinery act. He asked also what happened if the driven pulley got overloaded and stopped; did the friction fire the rope?

Mr. F. Preston replied that he had made enquiries at the mills he had visited, whether there had been any accident in the use of the ropes: and he found that in no case had there been any serious accident. Breakages of ropes had occurred, but in every case the rope quietly fell to the ground and did no damage. The ropes were about 6 in. circumference, and in most cases they had been running several years without a single breakage. He had never heard of an instance of the driven pulley being overloaded and stopped and of the rope slipping upon it; it was considered desirable to have a rope or two more than might be actually required for the power to be transmitted, so that there might still be ropes enough remaining to do the work, in case of accident to any one of them.

Mr. J. Musgrave, referring to the remarks made about the advantage of semicircular U grooves instead of V grooves for the ropes to work in, thought that if the large driving flywheels were grooved in that way with semicircular grooves, and the driven pulleys with V shaped grooves because of their smaller diameter, it would make the ropes last much longer than if both the driver and the driven pulley were made with V grooves. This was a suggestion that he had not heard before, but he thought the plan would answer very well.

Mr. Durie said he had purposely avoided going into any theoretical investigations in the paper, having desired simply to bring forward practical results, in order to give some idea of what really had been done in regard to rope gearing. He hardly thought it necessary to go into the question of the long formulæ which had been submitted in the discussion, because if the coefficient of friction was ascertained in one case it was almost impossible to ascertain it in all cases, and there appeared to be a great uncertainty. The value of the formulæ depended upon the assumption that the coefficient of friction was correctly known; but if it was wrong, then the results obtained from the investigation were wrong as well.

Then there was another question, namely, the proper amount of tension to be put upon the rope. There were two points to be taken into consideration: one that the proper amount of friction should be given to the motive power; and the other that the rope should last a sufficiently long time. It was generally found that if too much tension was put on the rope it would not last so long; it was simply a matter for consideration as to the length of time that the rope was wished to work; if the pulleys were limited in width, so that there was not room to put more ropes, then a heavier tension had to be put upon the ropes in order to get the driving power required, but they were not in that case expected to last so long.

With regard to the adoption of this plan of driving in rolling mills, that was simply a suggestion that had occurred to him in consequence of having heard that large straps were used for the purpose in America. The objections urged against ropes would apply equally he thought to straps; and if rolling mills could be driven with straps he should conclude that they could be driven with ropes better.

The form adopted for the rope grooves, as shown in the drawing, had been the result of a good deal of experience; it had answered satisfactorily in a great many cases, and he had not the slightest doubt that it would answer in others. As to the use of round grooves instead of angular ones, there was no doubt that the ropes would last longer with round grooves; but the friction would be much less, and it would be necessary to put a greater number of ropes; and then it would be simply a question of putting say half the number of ropes and their lasting half the time, or putting double the number of ropes and their lasting double the time. With regard to the suggestion to make one pulley with V shaped grooves and the other with semicircular grooves, he was not able to give any opinion at present on that point.

In reference to the splicing of the ropes, it was desirable to point out that it was essential the splice should be of sufficient length to avoid increasing the diameter of the rope. In the specimen exhibited of a rope that had been newly spliced it would be seen that there was not much difference in the diameter at the splice,

and after it had been working for a little while there would be very little difference in the diameter at that part. The other specimen of rope exhibited had also been spliced, and had since been working $4\frac{1}{2}$ years, and in this hardly any difference in the diameter could be seen at the splice.

The President moved a vote of thanks to Mr. Durie for his paper, which was passed.

The Meeting then terminated.

A shell made of fluid-compressed steel was shown by Sir Joseph Whitworth, which had penetrated 16 in. of iron armour plate and 12 in. of oak backing, with scarcely any mark left upon the shell from the work it had done; one of the edges had been polished to show the perfect soundness of the metal. The shell was 808 lb. weight, and made to contain a bursting charge of 20 lb. of powder, but had been fired without any bursting charge. to test its power of penetration; the trial took place at Gâvre in France. The form of the shell was hexagonal, 11·92 in. diameter at the angles and 10·92 in. at the sides, and flat-headed, that being found the best form for penetrating armour plates when struck at a considerable obliquity, and the only form which will go straight through water or penetrate below the water line.

A new construction of elastic wheels for road carriages was also shown by Sir Joseph Whitworth, having light curved steel spokes that gave an elastic yielding of the wheels as the carriage rolled along.

The large works in progress of the new City Hall were also shown to the Members by invitation of the Mayor of Manchester.

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